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Frequency of After-Shocks
and
Space-Distribution of Seismic Waves.¹⁾

By

S. Kusakabe, *Rigakushi.*

With one plate.

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Introduction.

As to the frequency of after-shocks, a hyperbolic formula was empirically obtained by Prof. F. Ōmori²⁾ about ten years ago. That his formula gives satisfactory results was adequately shown by him in his valuable paper “On the after-shocks of earth-

1) An abstract of this paper may be found in the Proceedings of the Tokyo Physico-Mathematical Society, Vol. II. No. II. May, 1904. The Pub. of the E. I. C. in F. L. No. 17, 1904.

2) F. Ōmori. This journal, Vol. VII.

quakes," in which the said formula was applied to the three great earthquakes which had then recently occurred in Japan. Lately, another formula in the form of a logarithmic function has been obtained by Mr. M. Enya,* founded on three assumptions. The result of a laborious calculation is given by him to show that the logarithmic formula is equally as good as the hyperbolic.

As to the space-distribution of after shocks, Professor Ōmori proposed the empirical formula

$$y=ab^{-r}$$

where a and b are constants, while r is the distance of an observing place from the seismic focus. As it is reasonable to regard the shocks as proceeding from the seismic focus, the iso-frequency curves would take the form of a series of concentrics around the focus, if the earth were a homogeneous solid. The existence of the so-called sympathetic shocks seems a mystery to anyone who adheres to the above view and assumes, without any reason, the surface intensity to be continuous.

As a matter of fact, however, the earthcrust is made up of rocks varying greatly in physical properties, each having its own density and elasticity. To make the variation more discontinuous, rocks of all geological ages have been mingled together—as it were, by a series of geological disturbances, and are scattered about through the earthcrust.

Consequently their space-distribution would never be expressed with any approximation to exactness by a formula which is a function of the distance alone.

The first step in a theoretical investigation of the frequency

* M. Enya. The Pub. of the E. I. C. (in Japanese) No. 35, 1901.

is to ascertain the cause of the after-shocks. It being a common rule that even phenomena of one and the same category may have different causes, so in the case of earthquakes probably several distinct causes should be recognized, for it is hardly to be supposed that all subterranean disturbances, differing as they do so widely in intensity and in duration, should be referable to any one common mechanical action. To what particular cause or series of causes any earthquake may be due is not, however, a question to be dealt with here.

It is generally accepted, as a matter of course, that an earthquake depends upon a sudden impulse due to the internal stress of the earth. But the *modus operandi* whereby that internal stress manifests itself in an impulse is a problem, which is by no means of little importance but which unfortunately is neglected in most cases where the wave motions of the earthcrust are discussed. Were the earth a cosmic body of perfect elasticity, as it is generally assumed by clever mathematicians, we might surely expect seismic waves to propagate after certain laws deduced by their subtle analysis.

But, in such a case as the above, how can the initial impulse at the seismic centre be excited by the internal stress itself? *Ut tensio, sic vis*, and consequently no matter whether we adhere to the Humboldt-Naumann volcanistic view, or to a tectonic hypothesis, as Hoernes called it, or to R. Falb's sidereal hypothesis,* so very gentle must be the changing of the earthcrust that, though incessant from day to day, it can really be proved only by means of careful observation.

To cause an earthquake, the strain must increase *per saltum*

* Grundzüge zu einer theorie der Erdbeben und Vulkanausbrüche, 1869.

after the accumulated stress has reached the necessary amount at the given point, where the seismic focus is situated. Again, if at the instant when the weak point gave way, all the strata, being released from their overstrained state, were to come to equilibrium at once and there were no residual strain which might recover with the lapse of time, the earthquake at that instant would be the only effect of the accumulated stress.

According to the intrinsic meaning of the name "After-shock," the nearest cause must be attributed to a residual disturbance in the geotectonic condition after the original shock has ceased. An earthquake not participating in this residual is not an after-shock but an independent earthquake. *To make clear once for all my own standpoint, I must say, that the actual imperfectness of the elastic properties of rocks which compose our planet appears to be the prime cause—all other causes being secondary relative to it—of after-shocks or rather of all earthquakes. Although the magazine of seismic energy is being constantly and steadily replenished by the incessant recovery of the rocks around the seismic centre from their overstrained yielding, the effects are intermittent and manifest themselves as aftershocks.*

As a matter of fact, the folding of rocks and other kindred phenomena pertaining to their manifold changes of shape are found in great abundance within the earthcrust. It may be a question whether such phenomena once occurred with great frequency in a short time under wholly plastic conditions while now-a-days, the crust being permanently set, they occur much less frequently; or whether they are not the results of yieldings, occurring from time to time, wrought by the continuous action of stress, and always ready to recover from the over-strained state.

If the latter were the case, it would not be wholly inconceivable that an overstrained portion of the earthcrust recovers gradually after its stress has been removed by the geological disturbance which caused the original earthquake. In such a case, to be sure, this phenomenon of recovery might be the prime cause of the after-shocks of the original earthquake, since the ultimate result of this phenomenon must be equal to that which may be produced by an oppositely directed stress.

Experimental Researches.

From an investigation by F. D. Adams and J. T. Nicolson,¹⁾ it is evident that even such a comparatively rigid rock as marble may become wholly plastic under suitable conditions. For instance, the diameter of a cylinder increased by 1.388 times its initial, bulged out under endpressure. Another instance where a plate of marble, resting horizontally on four posts at the corners, in the course of about half a century, was considerably bent by its own weight, is reported by T. J. J. See.²⁾

As to yielding and recovery in the case of torsion of rocks, the author published some experimental results two years ago,³⁾ and proposed a logarithmic formula to express the amount of yielding and recovery from it at any instant. To cite some of the results:—(1) The amount of yielding increases proportionally to the logarithm of the time during which the couple

1) An experimental investigation into the flow of marble. Phil. Trans. of the R. S. A. Vol. 195, 1901.

2) The secular bending of a marble slab under its own weight. Nature, Nov. 20, 1901.

3) Pub. of the E. I. C. in F. L. No. 14, 1903. Tokyo. This journal, Vol. XIX, Art. 6, 1903.

acted; (2) the residual surviving the couple after it has been withdrawn increases with the increase of the time during which the couple acted on the specimen; (3) the residual diminishes with the lapse of time and ultimately wholly disappears after an infinite time, i.e. rocks from instant to instant recover from their yielding to overstrain.

In the case of flexure,* though it is not so enormous as in the case of torsion, the phenomena of yielding and of recovery are sufficiently great to be dealt with. To give one instance; in a piece of sandstone which was loaded with 3000 grams-weight, the amount of bending was $\alpha = 27.95 \times 10^{-4}$ radians at the instant of loading. The latter quantity, however, increased to $\alpha = 33.86 \times 10^{-4}$ after $3\frac{2}{3}$ hours and to $\alpha = 60.57 \times 10^{-4}$ after about sixteen hours. Further increase of the flexure could be distinctly observed during about two weeks till at last the yielding, though it was still steadily increasing, was much obliterated by the influence of the temperature-change.

After about two weeks, i.e. 20363 minutes, the specimen was unloaded and the amount of residual bending was observed from instant to instant. As in the case of torsion, it recovered gradually and incessantly. The result of the experiment is given in the following table.

* For the method of measurement and other details the reader is referred to the author's papers: Pub. of the E. I. C. in E. L. No. 17. Tokyo, and this journal. Vol. XX. Art. 9. 1905. An abstract is also given in Proc. of the Tokyo Physico-Mathematical Society, Vol. II. No. 11.

Specimen No. 3 _p . Sandstone. $a=1^{\circ}153$, $b=1^{\circ}120$, $l=10^{\circ}0$ $\rho=2.20$			
Loaded at 4 ^h 27 ^m P.M. 9 th Feb. 1903. $M=3000$ grs. $M_0=3300$ grs.			
Unloaded at 7 ^h 50 ^m P.M. 23 rd . $M=0$. $M_0=3300$ grs.			
Time.	Recovery.	Time.	Recovery.
23 rd P.M. 7 ^h 51 ^m	20.87×10^{-4} radians.	24 th A.M. 8 ^h 3 ^m	25.91×10^{-4} radians.
52	21.59	P.M. 1 38	27.50
55	21.87	3 15	28.30
57	22.02	5 34	29.28
8 0	22.30	6 43	31.09
4	22.51	7 14	31.27
6	22.37	8 18	31.47
9	22.59	9 41	31.84
17	22.69	25 th A.M. 10 0	34.44
24	22.95	P.M. 6 42	37.63
57	23.32	27 th A.M. 8 12	45.27
9 35	24.52	P.M. 5 28	47.38

Thus the amount of recovery increased, in the course of about four days, to more than twice its initial value.

Frequency of After-Shocks.

From what has been explained in the above section we know, as a matter of fact, that a piece of rock yields under the constant action of stress, and also that the residual strain surviving the stress diminishes from instant to instant. This last phenomenon must be the prime cause of the after-shocks. Thus, the first step is to find some formula expressing the rate of recovery, or the rate with which the residual varies with time. One form of such

a formula, however, was lately deduced from the logarithmic law of yielding, as it was given in the author's papers above cited. The formula is

$$\rho = k \log \frac{F'(2\rho+1) [F'(\rho+t+1)]^2}{[F'(\rho+1)]^2 F'(2\rho+t+1) F'(t+1)}$$

where* ρ is the total amount of recovery at the instant t , both ρ and t being reckoned from the instant when the external force is wholly withdrawn, while k and p are constants, of which the former specifies the rock and the latter the time-lapse required by the force to attain its maximum.

Let F be the frequency, then if c is a constant, we have

$$\begin{aligned} F &= c \int_{\rho}^{\rho} \frac{1}{t} dt \\ &= c k \log \left\{ 1 + \frac{\rho^2}{(2\rho+1) + 2(\rho+1)t + t^2} \right\}. \end{aligned}$$

Thus we have a logarithmic form for the frequency of after-shocks. A little consideration of the nature of the constant p will make it reasonable to neglect the term $\frac{t^2}{\rho^2}$ so long as t is not very large. Then we have, for first approximation,

$$F = k' \log \left\{ 1 + \frac{1}{A + Bt} \right\}$$

which is the same as that of Mr. Enya. Again, expanding the logarithmic function and taking its first term only, we have Prof. Ōmori's formula

$$F = \frac{k''}{h+t}.$$

Though the resulting formulæ for the frequency are tolerably well formed inasmuch as they were tested by Prof. Ōmori and

* The symbol Γ stands for Gamma-function which may be found in any text-book in integral calculus. When p is a positive integer we have the relation $\Gamma(p+1) = 1, 2, 3, \dots, (p-1) \cdot p$.

Mr. Enya, the original formula for the recovery is not wholly beyond question. The assumptions under which the formula is deduced are very far from what is actually the case in an earthquake. The force acting on the rock is assumed to increase intermittently, and, what adds to the difficulty, it is assumed to be withdrawn not suddenly but slowly and intermittently. The following may be closer to the actual case.

Whatever view may be adopted as to the origin of the seismic energy, it is reasonable to consider the force as increasing constantly with time, i.e.

$$df = k dt$$

where k is a constant, and attaining a sufficient amount F it acts suddenly to cause an earthquake at the time T , so that we have

$$F = k T.$$

Suppose the logarithmic law of yielding, which was experimentally established in the last series of experiments, to be granted, so that

$$dz = K df \log \{t + \tau\},$$

where z is the amount of yielding and K a constant specifying the kind of rock, while τ is a constant referring to the choice of origin of time t . Then we have

$$z = K k \int_0^T \log (t + \tau) dt.$$

If the total force F is suddenly withdrawn at the instant $t = T$ when the original earthquake is supposed to have taken place, it may be easily proved that the residual strain at any instant $t = T + t'$ is given by

$$\sigma = k K \{T + t' + \tau\} \log \left\{ \frac{T + t' + \tau}{t' + \tau} \right\}.$$

Now, as the frequency is assumed to be proportional to the rate of recovery, we have

$$F = -c \frac{d\sigma}{dt} \\ = \frac{c \cdot k \cdot K \cdot T}{t + \tau} - c \cdot k \cdot K \cdot \log \left\{ 1 + \frac{T}{t + \tau} \right\},$$

where τ , c , k , K and T are all constants, and t is written for t' whose origin may be any instant, provided the proper value is given to the constant τ .

Here the frequency F may be considered to be composed of two terms F_1 , which is hyperbolic and F_2 which is logarithmic, so that h being a constant

$$F_1 = \frac{h}{t + \tau}, \\ F_2 = \frac{h}{T} \log \left\{ 1 + \frac{T}{t + \tau} \right\} \\ F = F_1 - F_2.$$

As the constant T is, in all probability, very great as compared with the other constants c , k and K , the main term is the first, so that the curve of frequency F is a little different from a hyperbola.

When h is given, the curve F_1 takes a definite form, but the curve F_2 is wholly indefinite so long as T , i.e. the time required by the force to become sufficient to cause the earthquake, is not known. *That is to say, if the time during which the causal agent of the earthquake existed is long, the curve of frequency approaches the hyperbola represented by F_1 , but it deviates more and more from the latter curve as the duration T diminishes. For example, the number of after-shocks of an earthquake of an explosive nature is necessarily smaller than that of an earthquake of geotectonic origin, and the frequency curve differs more from*

a hyperbola in the one case than in the other. It is well known fact that the most characteristic which distinguishes tectonic quakes from volcanic ones is found in very numerous after-shocks. The numerical example given below will show this more clearly.

$h=1000; \tau=1$		F_2		F'	
t	F_1	$T=100$	$T=1000$	$T=100$	$T=1000$
1	500	39	6	461	494
2	333	35	6	298	327
3	250	33	6	217	244
4	200	30	5	170	195
5	167	29	5	138	162
6	143	27	5	116	138
7	125	26	5	99	120
8	111	25	5	86	106
9	100	24	5	76	95
10	91	23	5	68	86
11	83	22	4	61	79
12	77	22	4	55	73
13	71	21	4	50	67
14	67	20	4	47	63
15	63	20	4	43	59
16	59	19	4	40	55
17	56	19	4	37	52
18	53	18	4	35	49
19	50	18	4	32	46
20	48	18	4	30	44
24	40	16	4	24	36
29	33	15	4	18	29
39	25	12	3	13	22

In the above example, suppose the unit of time to be one month, then the number of after-shocks during the first, second, third, month etc., would be either 461, 298, 217, etc. or 494, 327, 244, etc. respectively, according as the time required by the force to accumulate to the amount sufficient to cause the earthquake was a hundred or a thousand months.

We may remark that the solution of the above formula gives a means of determining the length of time required to generate that earthquake, and this must, at least, elapse before the region to which it refers is again disturbed by a similar catastrophe.

A few words may be inserted here in reference to the situation of the centre of after-shocks. It may appear, *prima facie*, that all of the after-shocks must necessarily proceed from the seismic focus of the original earthquake. But this is not necessarily so, and it does not actually happen, that the centres of the after-shocks and those of the original earthquakes coincide with one another.

From the above theory of yielding, however, it comes to be the common rule rather than an exception that they do not generally coincide. The seismic focus of the original earthquake is, of course, a region where the stratum giving way to the internal stress, was crushed or dislocated, e.g., in the case of a tectonic earthquake. All the after-shocks, however, are the result of recovery from the yielding so that they take place most frequently where the rate of recovery is the greatest. No doubt, a region once dislocated can never recover so as to cause any after-shocks. *Of the neighbouring regions, that part which consists of rocks most capable of yielding and recovery is most likely to become the centre of after-shocks. Hence, though the after-shocks are the residual effects of the original earthquake, the*

centre of them will be transferred elsewhere to some neighbouring weaker region.

To give an example, in the case of the Mino-Owari earthquake,¹⁾ which was caused by a sudden falling of the Palaeozoic strata on the right wing along the line of the 'fault of Neo,' accompanied by lateral shifting toward the north-west,²⁾ the centre of the after-shocks was transferred considerably southward³⁾ to the lowland of Mino and Owari, which is believed to have been recently formed out of the sediments of the confluent streams, the Kiso and the Nagara.⁴⁾

Iso-Frequency Curves of After-Shocks.

The discussion in the last section refers to the frequency of after-shocks in the very centre of the disturbance. Here a hint is given to show how the geological distribution of rocks plays the greater part in diversifying the form of iso-frequency curves, which would all be similar to each other if the earth were a homogeneous isotropic body.

It is a matter of course that a seismic wave propagating through a medium having a greater hysteresis fades more rapidly than one propagating through another medium having a less hysteresis. That is to say, the distance between two successive iso-frequency curves should be dependent on the geological distribution of the rocks in the region. *Not only is the frequency*

1) A short description is given in Professors B. Kotō's and F. Ōmori's papers cited below.

2) B. Kotō. On the cause of the Great Earthquake in Central Japan, 1891. This journal, Vol. V. p. 353.

3) F. Ōmori. On the After-shocks of Earthquakes. This journal, Vol. VII.

4) B. Kotō. Loc. cited. p. 307.

dependent on the geological nature of the region under consideration, but it must be greatly affected by the geological distribution of the rocks lying between the seismic focus and the said region.

In other words, the seismic-wave-conductivity, if we may be allowed to employ such a term from some analogies in heat and electricity, may be different for different rocks, so that in one direction an earthquake may be propagated with comparatively smaller fading than in another direction.

Now, as was experimentally shown by the author himself,* the amount of hysteresis generally decreases with an increase of the elastic constants, while the latter increase with their age of formation. Although nothing, as yet, can be said about any numerical relation between hysteresis and the age of formation of different rocks, yet in the rocks so far examined, a certain relation seems to exist.

To illustrate this fact, the hysteresis curves for a few specimens of rocks are shown in Figs. 2 and 3. If there were no hysteresis, the curve would, of course, shrink to a single line, so that the amount of hysteresis may be conventionally compared by the area enclosed by the curve. It is, then, a matter of fact that the area is enormously great for new rocks such as sandstone and rhyolite, and gradually diminishes as rocks of older ages are examined, until it becomes very small for the oldest rocks of the Archaean age. Thus it would not be a wild conjecture to say that the amount of hysteresis gradually diminishes from Cainozoic, through Mesozoic and Palaeozoic, to Archaean rocks, in a definite, though not yet ascertained, ratio.

An inference to be drawn from the above is that the seismic

* This journal, Vol. XIX, Art. 6, and Vol. XX, Art. 9. The Pub. of the E. I. C. in F. L. Nos. 14 and 17. Tokyo.

wave conductivity is least for Cainozoic rocks, and increasing step by step from Mesozoic to Palaeozoic, it becomes several times greater for Archaean rocks. Hence, provided the frequency of after-shocks at the seismic focus be given, the frequency at any place having a given distance from the seismic focus increases with the geological age of the rocks forming the path of the wave between the focus and the place.

In support of the above statement, I may cite the case of the Mino-Owari earthquake. Seismologists have never enjoyed so good an opportunity as that afforded them by the convulsion in the Mino-Owari plain, of observing an enormous number of after-shocks at a multitude of stations well distributed around the seismic centre. After the catastrophe of October 28th, 1891, the after-shocks were extraordinarily frequent or almost incessant: indeed, 1503 of them occurred during the remaining two months of that year, and during the next year 867 were recorded in the Meteorological Station of Gifu. The number of observing stations for these seismic waves, on the other hand, amounted to thirty-three in all, i.e. 14 in Mino, 9 in Owari and 10 in Mikawa Province.

Four curves of iso-frequency carefully drawn—irrespective, of course, of the geology of the regions—by Prof. F. Ōmori* are shown, with the corresponding geological distributions of rocks supplied by the author himself, in Fig. 1. The iso-frequency curve for $F=500$ lies wholly within Quaternary rocks and is in an elongated form extending nearly north and south between Gifu and Nagoya. The central region of the after-shocks may be in a similar form. The succeeding curves, however, so far

* F. Ōmori. Loc. cit.

from being similar to the first, are in quadrantal forms. In the western part, indeed, where the curves lie within Quaternary rocks, they are all parallel to each other; but in the other three directions they shrink in or swell out with all possible irregularities.

These irregularities, however, become regular when the geological distribution of rocks in the corresponding regions is taken into account. To express this in the form of a simple rule, the curve swells out where Paleozoic, or better Archaean rocks, predominate, and shrinks in where Cainozoic rocks prevail. This simple law is sufficiently satisfied up to very minute portions, as the figure proves most clearly.

As a corollary, since the geological map indicates only the surface distribution of rocks, we may conclude that the seismic wave is mainly transmitted through the earth's surface, or more probably, seismic action is mainly due to surface waves discussed by Lord Rayleigh, and recently propounded by Lamb for isotropic media. Any further discussion, however, as to the seismic wave conductivity of different rocks requires more precise quantitative investigation of the amount of hysteresis for these rocks, which may possibly prove a life-long problem.

Seismic Frequency and Degree of Damage in a Given Region.

It will not be entirely out of place to insert here discussions on a topic relating to seismic frequency and the degree of damage in a given region, in order that above statements may not be misunderstood. Of the above conclusions, relating to frequency, the one concerns the frequency of after-shocks at the central region of a given earthquake, while the other relates to the case

where the seismic centre is outside the region which we are considering. Any one who has any knowledge of astronomy knows that the ratio of the numbers of eclipses of the moon and of the sun theoretically observable at a given observatory differs from the actual number of eclipses known to occur.

Similarly, though of a wholly different nature, the actual frequency at a given station may be different from that indicated in the above sections of this paper. A certain region, notwithstanding the scarcity of the quakes originating in it, may be frequently visited by seismic waves proceeding from the surrounding districts. Again, one region may be shaken so slightly as to escape attention, while the other weaker region is violently damaged by the same seismic energy.

A complicated case such as the above, may be most clearly illustrated by analogy taking the case of heat. Let four thick pieces of copper (A , C) and lead (B , D) be arranged side by side as in the annexed figure. Suppose we heat the system at a point p to a high temperature, sufficient to melt the greater part of the lead piece B , but little of the copper piece C . Then, taking into account the heat conductivity and melting point of the two metals, we may easily so adjust the breadths of the pieces B and C , that the lead piece D also melts in the part where it is in contact with the copper piece C , though the latter does not participate in the melting. The remaining piece A , though it is nearly as distant from the source of heat as the

Copper.	Lead.	Copper.	Lead.
A	B	p C	D

lead piece *D*, may be only slightly heated by virtue of the bad conductivity of the lead piece *B*.

The high degree of heat conductivity in copper, is analogous to the small hysteresis of old rocks*, while the low melting point of lead corresponds to the inferior elasticity of new rocks. To say that, copper being a good conductor, may be easily heated even when the source of heat is remote, is wholly different from saying that it may be often melted under the same conditions. Although lead melts very easily, it does not conduct heat very well, so that even the portion comparatively near to the source of the heat may remain solid. But it is so only when the part intermediate between it and the source is also lead. If the intervening metal is copper, the case is reversed.

All these complicated phenomena find their analogy in the case of seismic waves. *Whether a region is frequently visited by seismic waves or is not can never be determined by the data relating to that region alone. A severe damage does not necessarily indicate that the epicentre of the earthquake lies near by. However great the destruction is, it is nothing more than the superficial effect of the earthquake which is wholly controlled by surrounding conditions. The main factor which determines the degree of disturbance is the geological distribution of the rocks in the whole domain.*

The existence of the so-called sympathetic shock or *Relais-beben* is also due to the reason just stated. In the above illustration, one who knew nothing of the thermal properties of the metals might call the melting of the lead piece *D* sympathetic.

* This is simply an analogy, conventionally adopted for sake of illustration. The general rule that an analogy, however perfect, does not explain all the facts connected with it, is true in this case.

The Mino-Owari earthquake gives a concrete instance which explains this phenomenon also. From B. Kotō's* valuable paper we may cite the geology of the domain.

The extensive and populous plain of Mino and Owari is on three sides bounded by mountains mainly of Palæozoic formation. Granite and schistose rocks make up the main blocks of the range. Beyond the mountain-ridge, in the north, lies a plain of considerable extent, where the Mesozoic formation is extensively developed, and later on has been intruded into in places by masses of Tertiary eruptions. The city of Fukui lies in the basin of the River Kudzuryū draining this plain.

Similarly, in the west, there lies a plain of recent geological era at the eastern border of Lake Biwa, the city of Hikone being the most populous one in the region. It was very remarkable that these two regions were severely shaken and greatly damaged by the earthquake, whereas the stretches of land between these and the Mino-Owari plain suffered very little.

Under the point of view in question, it means simply that the Palæozoic rocks, having less hysteresis, conducted the seismic wave very well but were not damaged by virtue of their high elasticity, while the Cainozoic rocks in contact with them, wholly absorbing the seismic energy, were severely shaken in consequence of their inferior elasticity and large hysteresis.

In conclusion, I wish to express my best thanks to Prof. H. Nagaoka for his kind guidance throughout the whole of this investigation.

* B. Kotō. Loc. cit. Geology and Topography of Mino and Owari.

Fig. 1.



Fig. 2.

*Comparison of Hysteresis
 in the case of torsion.*

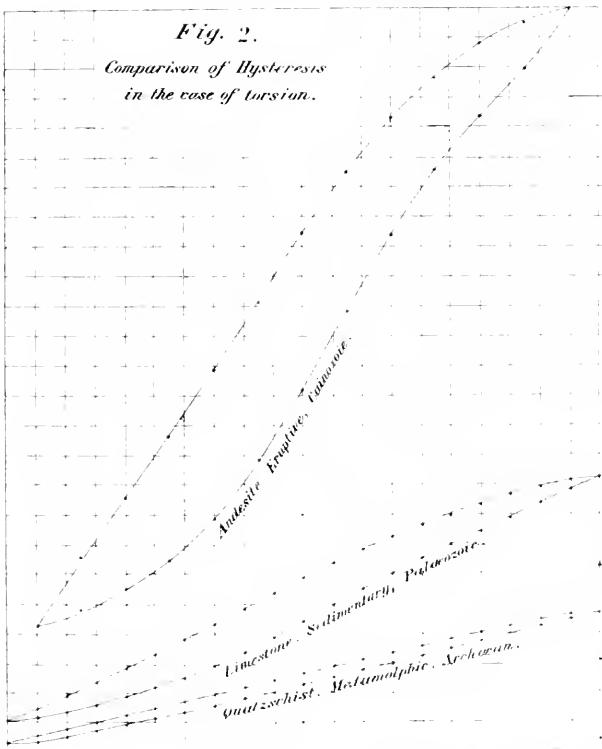
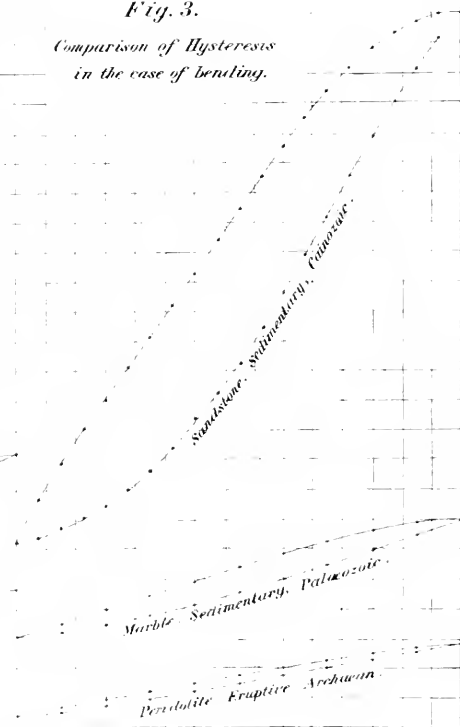


Fig. 3.

*Comparison of Hysteresis
 in the case of bending.*



Fossils from the Environs of Tōkyō.

By

S. Tokunaga,* *Rigakuhakushi.*

With 6 plates.

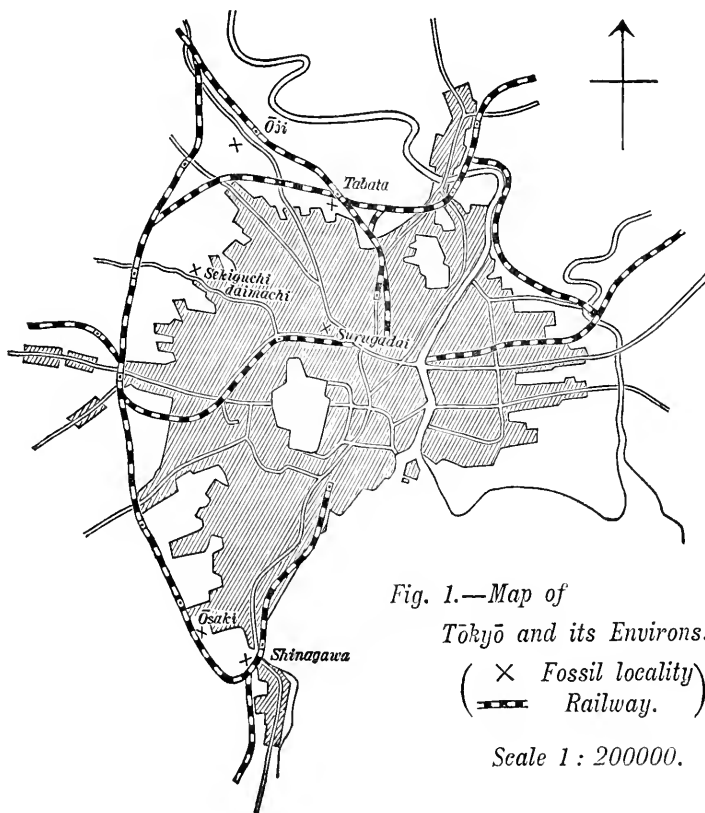
Introduction.

The Mesozoic palæontology of Japan has been studied by many authors, such as MOJSISOVICS, NEUMAYR, YOKOYAMA, JIMBŌ, YABE, NATHORST, GEYLER etc.; but that of the Cainozoic group has received comparatively little attention. The only author who has written about its plant fossils is NATHORST, who recognized in them both Miocene and Pliocene forms. On the Molluscan remains, BRAUNS' "*Geology of the Environs of Tōkyō*"** is the principal work. Its author studied shells collected chiefly at Shinagawa and Ōji, and described them as Pliocene. In the same work he also added a few notes on fossils from various other localities. After more than three years' careful study of these so-called Japanese Pliocene fossils, I have arrived at a conclusion differing from BRAUNS'. I have been several times at Ōji, Shinagawa and Tabata, and the number of species I have collected far exceeds that mentioned in BRAUNS' list. The collected specimens are now all preserved in the Science College.

* Formerly Yoshiwara.

** Memoirs of the Science Department, Tōkyō Daigaku, No. 4, 1881.

Tōkyō is situated on the southern extremity of an extensive Diluvial plain of the Kwantō district which is bordered on the north and west chiefly by Palæozoic mountain ranges, and on the east and south by the sea. On the SE and SSW, there are two long peninsulas, Miura and Kazusa-Awa, both projecting southward and consisting chiefly of inclined Pliocene tuff layers. Everywhere in the plain, there is found a thick stratum



of loam underlaid by gravel and sand. This sand is rich in fossils especially in localities to the east and north-east of Tōkyō. The greater part of these localities yield fossils of the “upper horizons,” while those of the “lower horizons” are found only

at a few places, such as Shinagawa, Ōji, Tabata, etc. Shinagawa is a southern suburb of the capital and is very near the sea; the fossils are found at the foot of a hill along a railway cutting. Ōji and Tabata lie at the foot of the northern continuation of a hill in Tōkyō, and at Surugadai in Tōkyō the same fossil horizon as at Tabata is exposed along the cutting of the Kandagawa. Besides, a few fossils of a still higher horizon are found in Tōkyō at Sekiguchi-daimachi and also at Ōsaki at the foot of a hill which is a northern extension of the one in Shinagawa which has been mentioned.

The present paper consists of two parts, descriptive and general. In the former, the shells are arranged according to the system adopted by Tryon in his "*Manual of Conchology*." The latter is a discussion of their geological age. Localities of shells mentioned either have been determined by my own observations or taken from works written by others, among which I may mention that of PILSBRY, which has proved to be very valuable.

Description of the Species.
Mollusca.

Gastropoda-Prosobranchiata,
Order Pectinibranchiata.

MURICIDÆ.

1. MUREX FALCATUS Sow.

Pl. I. Fig. 1.

TRYON, Man. Conch., p. 127.—Proc. Zool. Soc., 1879, p. 181.

Synonym.—*M. aduncus* Sow.; *M. acanthophorus* A. AD.

Shinagawa (frequent).

Living: Hakodate (Hokkaidō), Tsusaki, Sumoto (Awaji),
Gotō-Islands, Kii, Kagoshima and Misaki (Sagami).

2. MUREX LONGICANALIS TOK.

Pl. I. Fig. 2.

Shell small, spiral, fusiform; whorls five, convex, crossed by numerous fine transverse striations; varices on each whorl nodulous, but not spinous; aperture oval, canal very long. Height 19^{mm}; breadth 9^{mm}.

Shinagawa (rare).

3. TROPHON EXIGUUS TOK.

Pl. I. Fig. 3.

Shell fusiform, but more broadly ovate than in the two preceding species; spire prominent; whorls with numerous, sharp, laminated varices, the interstices spirally ribbed; aperture ovate; canal open.

Trophon has hitherto been known as an essentially boreal genus.

Shinagawa (very rare).

Some living specimens were collected at Nanao (Noto).

4. **RAPANA BEZOAR** L.

LISCHEKE, Jap. Meeres-Conch., Vol. I., p. 51.—TRYON, Man. Conch., II., p. 202.—MORSE, Shell-Mound of Ōmori, p. 34.—BRAUNS, Geol. Env. Tōkiō, p. 51.

Shinagawa, Tabata and Ōji (many).

Living: Tōkyō, Yokohama, Yokosuka, Misaki (Sagami), Shimoda (Izu), Hakodate, Ise, Kōbe, Higo, Nagasaki, Tosa, Kagoshima, China and Philippines.

TRITONIDÆ.

5. **TRITON SAULIE** L.

Pl. I. Fig. 4.

LISCHEKE, Jap. Meeres-Conch., I., p. 45.—TRYON, Man. Conch., III., p. 10.—SYST. Conch. Cab., III., 2, p. 171.

One fragmentary specimen of this species, which is very common in Japan, was found at Shinagawa.

Living: Tōkyō, Misaki (Sagami), Hitachi, Awaji, Nagasaki Tateyama (Awa), Setouchi (Inland sea in Japan), Takanoshima, Luzon (Philippine), Mauritius (Indian Ocean), Natal (South Africa) and Galapagos (South America).

FUSIDÆ.

6. **FUSUS NODOSO-PLICATUS** DKR.

Pl. I. Fig. 5.

LISCHEKE, Jap. Meeres-Conch., I., P. 33, II., p. 27.—Proc. Zool. Soc.,

1879, p. 181.—DUNKER, Nov. Conch., p. 11.—SYST. Conch. Cab., III., 3, p. 190.

Shinagawa (abundant).

Living: Yokohama, Misaki (Sagami), Nagasaki, Gotō-Is., Sumoto (Awaji), Mogi (Hizen) and Tomonotsu (Bingo).

7. FUSUS PERPLEXUS A. AD.

Pl. I. Fig. 6.

MORSE, Shell-Mound of Ōmori.—LISCHKE, Jap. Meeres-Conch., I., p. 34, II., p. 26.—SYST. Conch. Cab., III., 3, p. 195.—BRAUNS, Geol. Env. Tōkiō, p. 55.

Synonym.—*F. inconstans* LISCHKE.

Shinagawa (many).

Living: Tōkyō, Hōjō (Awa or Bōshu), Yokohama, Aomori (Mutsu), Hakodate, Izugahara (Tsushima), Gotō (Hizen), Mogi (Hizen), Tosa, Futamigaura (Ise) and Nagasaki.

8. FUSUS SIMPLEX E. A. SMITH.

Pl. I. Fig. 7.

Proc. Zool. Soc., 1879, p. 202.

Ōji (very rare).

Living: South of Corea.

9. FUSUS SR.

Shell oval, small; spire short, 3-whorled, not plicate nor varicose, finely striated in the transverse direction on the last whorl; aperture oval; canal short. Probably this is a young form of a species different from the three preceding ones. Height 15^{mm}; and breadth 8^{mm}.

Ōji (very rare).

Living specimens were collected at Misaki (Sagami).

BUCCINIDÆ.**10. HEMIFUSUS TERNATANUS Gmel.**

Pl. I. Fig. 8.

TRYON, Man. Conch., III., p. 112.

Shinagawa (rare).

Living: Chōshi (Shimōsa), Hōjō (Awa or Bōshu), Ajiro (Izu), Mogi (Hizen), Akune (Satsuma), Philippines and Indian Ocean.

11. NEPTUNEA DESPECTA LINNÉ.

SCHRENCK, Moll. Amurl. and Nord-Japan. Meeres.—TRYON, Man. Conch., II., p. 116.—LISCHKE, Jap. Meeres-Conch., I., p. 37.—SYST. Conch. Cab., III. 3, p. 107.—VERHAND. Russ-Kais. Miner. Gesell. St. Petersburg., II. Series, XXXVIII. Band, 1, 1900.

Synonym.—*N. arthritica* VAL.

Shinagawa and Ōji (frequent).

Post-pliocene of Murman and White Seas (North of Russia).

Living: Hakodate, Aomori, Hidaka, Nemuro, Gulf of Tartary (North Asia) Castries Bay (North Asia), East and West coast of Sakhalin, and White and Murman Seas (Russia).

12. SIPHONALIA CASSIDARÆFORMIS RVE.

Pl. I. Fig. 9.

LISCHKE, Jap. Meeres-Conch., I., p. 38.—PILSBRY, Catal. Mar. Moll. Jap., p. 28.

Shinagawa (frequent).

Living: Hakodate, Enoshima (Sagami), Shimoda and Oshima (Izu), Kōchi (Tosa), Nagasaki and Gotō Islands.

13. **BUCCINUM UNDATUM** LINNÉ.Pl. I. Figs. 10 *a* and *b*.

Syst. Conch. Cab., III. 1, p. 15 and 31.—WOOD, Crag Moll., p. 35.—
 TRYON, Man. Conch., II., p. 173.—SOWERBY, Genera rec. and fos.
 Shells.—VERHARD, Russ.-Kais. Miner. Gesell. St. Petersburg., II.
 Series, XXXVIII. Band, 1, 1900.

Synonym.—*B. littoralis* KING.—*B. striata* SOW.—*B. ochotense* MIDD.—
B. pelagica KING.—*B. zitlandica* FORB.

The species of this genus are all restricted to the boreal seas. No living specimens are found south of Hakodate. Though my specimens differ in some points from the descriptions given of *Buccinum undatum* LINNÉ in several works consulted, yet I believe they are only a varietal form of the species, for it is known as very variable in form.

Shinagawa (abundant), Ōji (rare).

Post-Pliocene of the northern coast of Russia (Murman Sea, White Sea and Nova Zembla).

Living: Hakodate, Kitami (Hokkaidō), Etorof, Siberia, Sea of Ochotsk, North Cape, White and Murman Sea (Russia), Baltic Sea, England, France, Iceland, Labrador, Newfoundland, Massachusetts, and Ocean to the south of New Jersey.

14. **VOLUTHARPA PERRYI** JAY.

Pl. I. Fig. 11.

MIDDENDORF, Sib. Reise.—ANN. Mag. Nat. Hist., III. 6. (1860), p. 109.

—TRYON Man. Conch., III., p. 173.—SYST. Conch. Cab., III., p. 95.

Synonym.—*V. paulucciana* TAP.

This genus has only seven species, all of which are restricted to the North Pacific Ocean, with the exception of the present, which is found living at Hakodate, Tōkyō Bay and Enoshima (Sagami).

Ōji (rare).

15. **EBURNA JAPONICA** Sow.

BRAUNS, Geol. Env. Tōkio., p. 64.—MORSE, Shell-Mound of Ōmori., p. 30.—TRYON, Man. Conch., III., p. 211.—LISCHE, Jap. Meeres-Conch., I., p. 67., II., p. 58.

Shinagawa and Ōji (frequent).

Living: Tateyama (Awa or Bōshu), Misaki (Sagami), Ōmori (in Tōkyō Bay), Enoshima (Sagami), Ajiro (Izu), Shimoda (Izu), Hakodate, Ōshima (Izu), Kamakura (Sagami), Tsusaki, Tsu (Ise), Tsuruga (Echizen), Sado, Nagasaki, Higo, Shigajima, Awa (Shikoku), Shimonoseki, Tosa and Kagoshima.

NASSIDÆ.16. **NASSA JAPONICA** A. AD.

BRAUNS, Geol. Env. Tōkio, p. 29.—LISCHE, Jap. Meeres-Conch., III., p. 37.—PILSBRY, Catal. Mar. Moll. Japan., p. 34.

Synonym.—*N. tenuis* SMITH.

Ōji, Tabata and Shinagawa (abundant).

Living: Tōkyō, Enoshima (Sagami), Uraga (Sagami), Ōshima (Izu), Seto-uchi (Inland sea in Japan), Kino-Ōshima, Sado, Izugahara (Tsushima), and Shima.

17. **NASSA LIVESCENS** PHILIPPI.

BRAUNS, Geol. Env. Tōkio, p. 29.—LISCHE, Jap. Meeres-Conch., II., p. 52.

Ōji and Tabata (frequent).

Living: Tōkyō, Ajiro (Izu), Kominato (Awa or Bōshu), Nagasaki, Kiu-shū, Enoshima (Sagami), Tsuruga (Echizen), Izugahara (Tsushima), China Sea, Manila (Philippines), Java and Indian Ocean.

MARGINELLIDÆ.18. **ERATO CALLOSA** AD. and RVE.

Pl. I. Fig. 12.

TRYON, Man. Conch., V., p. 9.—PILSBRY, Catal. Mar. Moll. Japan., p. 52.—SYST. Conch. Cab., V. 4, p. 146.

Shinagawa (rare).

Living: Tōkyō Bay, Nagasaki and China Sea.

OLIVIDÆ.19. **OLIVELLA CONSOBRINA** LISCH.

Pl. I. Fig. 13.

BRAUNS, Geol. Env. Tōkio., p. 29.—PILSBRY, Catal. Mar. Moll. Japan, p. 23.—LISCHKE, Jap. Meeres-Conch. II., p. 62.—SYST. Conch. Cab., V. I, p. 153.

Synonym.—*O. fabula* MARRAT.

Ōji (rare).

Living: Tōkyō, Enoshima (Sagami), Kamakura (Sagami), Hakodate, Yamada (Ise), Nagasaki and North coast of Tango.

COLUMBELLIDÆ.20. **COLUMBELLA MARTENSI** LISCHKE.

LISCHKE, Jap. Meeres-Conch., II., p. 47.—TRYON, Man. Conch., V., p. 130.—BRAUNS, Geol. Env. Tōkio, p. 29.

Brauns took the specimens of this species from Ōji as identical with *Collumbella scripta* LINNÉ of the Mediterranean Sea, but the former is clearly distinguished from the latter by the epidermal coloring. *C. scripta* LINNÉ has a yellowish-white epidermis, usually marbled or longitudinally 'broadly' striped

with chestnut or chocolate colour; while in *C. martensi* LISCHKE, the color is whitish with 'undulating lines' or flames of chestnut, and frequently articulated bands at the suture and on the middle and base of the body-whorl. In our specimens the coloring of the epidermis is distinctly preserved, so that our identification is quite certain.

Shinagawa, Ōji and Tabata (abundant).

Living: Tōkyō, Enoshima (Sagami) and Nagasaki.

21. COLUMBELLA PUMILA DKK.

Pl. I. Figs. 14 *a* and *b*.

DUNKER, Moll. Jap., p. 6.—TRYON, Man. Conch., V., p. 150.—PILSBY, Catal. Mar. Moll. Jap., p. 38.

Tabata (very rare).

Living: Tōkyō, Kamakura (Sagami) and Nagasaki.

CANCELLARIIDÆ.

22. CANCELLARIA SPENGLERIANA DESH.

Pl. I. Fig. 15.

TRYON, Man. Conch., VII., p. 67.—PILSBRY, Catal. Mar. Moll. Japan, p. 21.—CHALL. Report, XV., p. 273.—SYST. Conch. Cab., V., p. 25.

Synonym.—*C. tritonis* Sow.; *C. undulata* Sow.

Ōji and Shinagawa (abundant).

Living: Enoshima (Sagami), Misaki (Sagami), Kominato (Awa or Bōshu), Shimoda (Izu), Chōshi (Shimōsa), Futamigaura (Ise), Tsu (Ise), Kōbe, Nagasaki, Wakanoura (Kii), Akashi (Harima), Setouchi (Inland sea), China, Philippines and Australia.

23. **CANCELLARIA NODULIFERA** Sow.

Pl. I. Fig. 16.

DUNKER, Index. Moll. Maris. Jap., p. 103.—TRYON, Man. Conch., VII., p. 68.—ANN. Mag. Nat. Hist., 1868, Vol. II., p. 368.—PILSBRY, Catal. Mar. Moll. Japan, p. 21.—SYST. Conch. Cab., V., p. 27.

Synonym.—*C. imperialis* MICH.

Ōji (rare).

Living: Yokohama, Shimizu (Suruga) and Kino-Ōshima.

TEREBRIDÆ.24. **TEREBRA BIPARTITA** GLD.

BRAUNS, Geol. Env. Tōkio, p. 34.—GOULD, Otia Conch., p. 126.—PILSBRY, Catal. Mar. Moll. Japan, p. 11.

Ōji and Shinagawa (rare).

Living: Enoshima (Sagami) and Hakodate.

25. **TEREBRA ALVEOLATA** HINDS.Pl. I. Figs. 17 *a* and *b*.

TRYON, Man. Conch., VIII., p. 23.—PROC. Zool. Soc., 1879, p. 183.—PILSBRY, Catal. Mar. Moll. Japan, p. 11.

Synonym.—*T. gotoensis* SMITH.

Shinagawa (rare).

Living: Enoshima (Sagami), Gotō Is. and Strait of Malacca.

26. **TEREBRA PRETIOSA** RVE.Pl. I. Figs. 18 *a* and *b*.

TRYON, Man. Conch., VII., p. 27.—DUNKER, Index Moll. Maris. Jap., p. 71.

Shinagawa (very rare).

Living: Enoshima (Sagami) and China.

27. **TEREBRA SUBTEXTILIS** E. A. SMITH.Pl. I. Figs. 19 *a* and *b*.

TRYON, Man. Conch., VII., p. 19.—PROC. Zool. Soc., 1879, p. 185 and p. 217.—PILSBRY, Catal. Mar. Moll. Japan, p. 11.

Shinagawa (very rare).

Living: Misaki (Sagami), Izu, Shikoku and Kii.

28. **TEREBRA** CFR. **SEROTINA** AD. and RVE.Pl. I. Figs. 20 *a*, *a'*, *b* and *b'*.

TRYON, Man. Conch., VII., p. 29.—PILSBRY, Cat. Mar. Moll. Japan, p. 11.

Shinagawa (very rare).

Living: Izu, Kii and Nagasaki.

PLEUROTOMIDÆ.29. **PLEUROTOMA OXYTROPIS** Sow.

Pl. I. Fig. 21.

TRYON, Man. Conch., VI., p. 168.—PILSBRY, Catal. Mar. Moll. Japan, p. 14.—CHALL. Rep., XV., 1886.—SYST. Conch. Cab., IV. 3, p. 27.

Synonym:—*P. nobilis* HINDS.—*P. leucotropis* AD. and RVE.—*P. albicarinata* Sow.

Shinagawa and Ōji (frequent).

Living: Tōkyō, Enoshima (Sagami), Hōjō (Awa or Bōshu), Oshima (Izu), China, Mauritius, Panama to Gulf of California.

30. **PLEUROTOMA VERETEBRATA** SMITH.

Pl. I. Fig. 22.

TRYON, Man. Conch., VI., p. 169.—PILSBRY, Cat. Mar. Moll. Japan, p. 14.—ANN. Mag. Nat. Hist., XV., p. 416.—SYST. Conch. Cab., IV. 3, p. 31.

Shinagawa (very rare):

Living in Japan.

31. **PLEUROTOMA (DRILLIA) PRINCIPALIS** PILSBRY.

Pl. I. Fig. 23.

PILSBRY, Catal. Mar. Moll. Japan, p. 16.

Shinagawa (abundant), Ōj, (rare).

Living: Enoshima (Sagami), Nanao (Noto), Katanoura (Kii),
Tsu (Ise), Inland Sea, Kagoshima and Aomori.

32. **PLEUROTOMA (DRILLIA) SUBAURIFORMIS** SMITH.

Pl. I. Fig. 24.

DUNKER, Index Moll. Maris. Jap., p. 24.—TRYON, Man. Conch., VI,
p. 207.—Proc. Zool. Soc., 1879, p. 195 and p. 217.—PILSBRY, Catal.
Mar. Moll. Jap., p. 16.—SYST. Conch. Cab., IV. 3, p. 199.

Ōji (rare).

Living: Tōkyō, Kamakura (Sagami), Moroiso (Sagami) and
Inland Sea.

33. **PLEUROTOMA (DRILLIA) RECIPROCA** GLD.

BRAUNS, Geol. Env. Tōkio, p. 33.—GOULD, Otia Conch., p. 135.

Ōji (abundant), Shinagawa (rare).

Living: Ōshima (Izu).

34. **PLEUROTOMA (DRILLIA) RARICOSTATA** SMITH.

Pl. I. Fig. 25.

TRYON, Man. Conch., VI., p. 202.—PROC. Zool. Soc., 1879, p. 192.—SYST.
Conch. Cab. IV. 3, p. 195.—PILSBRY, Cat. Mar. Moll. Japan, p. 19.

Shinagawa (frequent).

Living near Nagasaki.

35. **PLEUROTOMA (MANGILIA) GRACILENTA** RVE.

Pl. I. Fig. 26.

TRYON, Man. Conch., VI., p. 251.—PROC. Zool. Soc., 1879, p. 195.—

PILSBRY, Cat. Mar. Moll. Japan, p. 19.

Synonym:—*P. contracta* RVE.—*P. fusoides* RVE.

Ōji (rare).

Living: Kamakura (Sagami), Tōkyō, East Coast of Kii, Philippines and North Australia.

36. **PLEUROTOMA (DRILLIA) TABATENSIS** TOK.

Pl. I. Fig. 27.

Whorls six, the upper three smooth, the rest only coarsely (about right) longitudinally costated with no trace of transverse ribs; shell distinctly angulated at the shoulder; aperture long, a little shorter than half the height of the shell. Height 4^{mm}; breadth 1.5^{mm}.

Tabata (very rare).

37. **PLEUROTOMA OJIENSIS** TOK.

Pl. I. Fig. 28.

Whorls eight, longitudinally costate and transversely liriate; costæ number fourteen or more, and are traceable to the base of the body whorl; liræ very fine and numerous, crossing the costæ as only fine striations; canal long, only a little shorter than half the height of the shell. Height 5.5^{mm}; breadth 2^{mm}.

Ōji (frequent).

38. **PLEUROTOMA SAGAMIENSIS** TOK.Pl. I. Figs. 29 *a* and *b*.

Shell more oval than in the two preceding species and turrated in form; oblique longitudinal costæ about twelve or more in number easily traceable from the upper suture line to the priphery in one whorl, but the lower half of each whorl usually devoid of the longitudinal plications; transverse liræ very distinct both on the costæ and in the interspaces; aperture oval, short, a little longer than one third the whole shell height. Height 30^{mm}; breadth 9^{mm}.

Shinagawa (very rare).

Living: Moroiso and Enoshima (Sagami).

39. **PLEUROTOMA (MANGELIA) PARVA** TOK.

BRAUNS, Geol. Env. Tōkio, p. 33.

Shell elongated, turriculated, acuminate; whorls seven, convex, with no any prominent angle near the suture; longitudinal ribs about nine or ten, somewhat oblique, crossed by transverse stiræ; canal lengthened; aperture narrow. Height and breadth 9^{mm} and 3.5^{mm}, or 7^{mm} and 2.5^{mm}.

Brauns determined the specimens as identical with *P. (Mangelia) striolata* PHIL. of Europe and Madeira, but the latter species is distinctly though narrowly shouldered, and has fine, almost microscopic spiral lines, while in our specimens these lines are coarser and distinctly visible to the naked eye. Besides the figures of the European species given in Wood's Crag Mollusca show many other differences.

Ōji (abundant).

DOLIIDÆ.

40. DOLIUM LEUTEOSTOMUM KÜSTER.

Pl. I. Fig. 30.

BRAUNS, Geol. Env. Tōkio, p. 60.—PILSBRY, Cat. Mar. Moll. Japan, p. 49.—TRYON, Man. Conch., VII., p. 261.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 401.—SYST. Conch., Cab., III. 1, p. 66.

Synonym :—*D. japonicum* DKR.—*D. variegatum* KÜSTER.

Shinagawa (frequent).

Living : Tōkyō, Misaki (Sagami), Hakodate, Nagasaki, Awa, in Shikoku, Satsuma and Indian Ocean.

NATICIDÆ.

41. NATICA CLAUSA DESH.

Pl. I. Fig. 31.

LISCHKE, Jap. Meeres-Conch., I., p. 81.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, I., p. 81.—WOOD, Crag Mollusca, I., p. 147.—ANN. Mag. Nat. Hist., 17. (1866), p. 274.—TRYON, Man. Conch., VIII., p. 30.—PILSBRY, Cat. Mar. Moll. Japan, p. 71.—MIDDENDORF, Mal. Ross. II., p. 91.—SYST. Conch. Cab., II. 1, p. 98.—Verhand. Russ.-Kais. Min. Gesell. zu St. Petersburg, II. Series, XXXVIII Band, 1, 1900.

Synonym :—*N. janthostoma* DESH.—*N. consolidata* COUTH.—*N. septentrionalis* BECK.—*N. vittata* JEFFREY.

Ōji and Shinagawa (abundant).

Pliocene :—Red Crag, Sutton, (England) ; Mammilian Crag, Brindlington, (England).

Quaternary :—

Post-glacial :—Kelsea Hill (England).

Lower-glacial :—Rockheath (England).

Middle-glacial :—Hopton and Billockby (England).

Upper-glacial :—Santa Barbada (California) ; San Pedro (California) ; northern part of Russia (Murman Sea, White Sea and Nova Zembla).

This living Species is decidedly circumboreal. It is known to be found in the following localities :—Hakodate, Bekkai, Kuriro, Akkeshi, Nemuro, Otaru, (all in North Japan), Sachalin, Kamtschatka, Kaojak, Ochotsk Sea, Schlanter Is., Nova-Zembla, Sitka (Alaska), Melville Is. (Arctic America), Vancouver, Greenland, Massachusetts and Maine. Lappland (Russia), Portugal and Arctic Europe.

Living specimens rarely found near Tōkyō, Awa (or Bōshu) and Chōshi (Shimōsa) seem to be the remnants of those numerous in the colder epoch.

42. NATICA AMPLA RVE.

Pl. I. Figs. 32 *a*, *b* and *c*.

BRAUNS, Geol. Env. Tōkio, p. 30.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 378.—LISCHE Jap. Meeres-Conch., I, p. 80.—MORSE, Shell-Mound of Ōmori, p. 66.—DUNKER, Index. Moll. Maris Jap., p. 61.—TRYON, Man. Conch., VIII., p. 33.—PILSBRY Cat. Mar. Moll. Japan, p. 71.—MORSE, Shell-Mound of Ōmori, p. 16.

Synonym :—*N. lamarekiana* RECL.—*N. didyma* BOLTON.—*N. vesicalis* PHIL.—*N. robusta* DKR.—*N. chemnitzii* RECL.—*N. petiveriana* RECL.—*N. intermedia* RECL.—*N. problematica* RVE.—*N. bicolor* SCHRENCK.—*N. incisa* DKR.

Ōji, Shinagawa and Tabata (frequent).

The living form is very common in Japan :—Tōkyō to Enoshima (Sagami), Awa or Bōshu, Chōshi (Shimōsa), Misaki (Sagami), Henda, Shibo, Kagoshima, Kure (Satsuma), Nagasaki, Hikata (Kii), Matsushima (Rikuzen), Uwajima, Futamigaura (Ise), Tsu (Ise), Awa in Shikoku, Kōchi (Tosa) and Kagoshima.

43. **NATICA PAPYRACEA** BUSH.

Pl. I. Fig. 33.

PHILIPPI, Abbild. u. Beschr. &c., II., p. 45.

Shinagawa (frequent).

44. **SIGARETUS PAPILLA** GMEL.

Pl. I. Fig. 34.

TRYON, Man. Conch., VIII., p. 58.—PILSBRY, Cat. Mar. Moll. Japan, p. 72.—LISCHE, Jap. Meeres-Conch., II., p. 169.—SYST. Conch. Cab., VI. 1, p. 36.

Synonym:—*S. costulatus* QUOY and GAINARD.—*S. acuminatus* A. AD. and RVE.—*S. coarctatus* RVE.—*S. nitidus* RVE.

Ōji and Shinagawa (rare).

Living: Tōkyō Bay, Nagasaki, Okinoshima (Kii), Nijima (Izu), China, Philippines, Tranquebar, Moluccas, Negro Is. and Red Sea.

SCALARIDÆ.45. **SCALARIA IMMACULATA** SOW.

Pl. I. Fig. 35.

TRYON, Man. Conch., IX., p. 61.—PILSBRY, Cat. Mar. Moll. Japan, p. 74.

Ōji (rare).

Living: Tōkyō Bay and Philippines.

46. **SCALARIA LAMELLOSA** LAM.

Pl. I. Fig. 36.

TRYON, Man. Conch., IX., p. 74.—PILSBRY, Cat. Mar. Moll. Jap., p. 74.—BRAUNS, Geol. Env. Tōkyō, p. 31.—WOODS, Crag Mollusca, I., p. 94.

BRAUNS identified the specimens of this species with *S. clathratula* MONT., found in the Crag as fossils and also living in the British Seas, at Madeira and New England. Though I can find no points of great difference by a mere comparison of our specimens with WOOD's figure, yet I deem it preferable to give it the name of *S. lamellosa* LAM. which is living in our waters; for the specimens of *Scalaria*, which is very rich in the number of its species, are often difficult to distinguish from one another by comparing figures only.

Tabata and Ōji (rare).

S. lamellosa LAM. was hitherto collected at Yokohama and Kamakura (Sagami), in the Mediterranean Ocean, near West Indies and Sandwich Islands.

47. SCALARIA ACUMINATA Sow.

Pl. I. Fig. 37.

TRYON, Man. Conch., IX., p. 83.—LISCHE, Jap. Meeres-Conch., II., p. 168.—BRAUNS, Geol. Env. Tōkio, p. 31.—WOOD, Crag Mollusca, I., p. 95, Suppl. p. 59.

BRAUNS ever named this specimen as *S. cancellata* BROCH. of the Coralline Crag of England.

Ōji (rare).

Living: Tōkyō and Malacca.

TRICHOTROPIDÆ.

48. TRICHOTROPIS UNICARINATA BROD.

Pl. I. Fig. 38.

TRYON, Man. Conch., IX., p. 44.—PILSBRY, Cat. Mar. Moll. Japan, p. 59.—BRAUNS, Geol. Env. Tōkio, p. 34.—SOWERBY, Genera Rec. and Fossil Shells.

BRAUNS called the specimens here referred to “*Trichotropis coronata* GLD.” but this Gould’s species is distinguished from *T. unicarinata* BROD. by having a narrower keel at the upper angle of the last whorl.

Trichotropis is known as living in the Arctic Seas.

Shinagawa and Ōji (rare).

Living: Hakodate and Yamada Harbour.

EULIMIDÆ.

49. EULIMA LEVIS TOK.

Pl. I. Fig. 39.

Shell small, white, polished, elongated and tapering; whorls smooth, flattened; suture ill defined, scarcely distinct; aperture longly oval, acuminate at the upper part; outer lip straight; inner lip slightly reflected; not umbilicated. Height 7^{mm}, breadth 1.5^{mm}.

Ōji (rare).

50. EULIMA OVALIS TOK.

Pl. I. Fig. 40.

This small shell is distinguished from the preceding species by its general form which is more ovate being 5^{mm} in height and 1.5^{mm} in breadth. Other characters are similar to the preceding.

Tabata (rare).

TURBONILLIDÆ.

51. TURBONILLA AFF. ELEGANTISSIMA MONT.

Pl. I. Fig. 41.

BRAUNS, Geol. Env. Tōkio, p. 32.—TRYON, Man. Conch., VIII., p. 322.
—WOOD, Crag Moll., Suppl., p. 184.

Synonym:—*Odostomia lactea* JEE.—*Chemnitzia jeffreysii* S. WOOD.

Our specimens seem to have more ribs than the European *T. elegantissima* MONT. figured by WOOD.

Ōji and Shinagawa (rare).

52. **TURBONILLA FUSCA** A. AD.

Pl. I. Figs. 42 *a* and *b*.

TRYON, Man. Conch., VIII., p. 356.—PROC. Zool. Soc., 1878, p. 864.

Ōji (rare.)

Living: Japan, Australia, Port Lincoln (Tasmania) Holdfast and Adringa Bay (near Adelaide in South Australia).

53. **TURBONILLA PAUCICOSTULATA** TOK.

The general features, the characters of the body-whorl, etc., are similar to those of *Turbonilla elegantissima* MONT., but our species has fewer rows of longitudinal ribs. Height 10^{mm}; breadth 3^{mm}.

Ōji (frequent).

54. **ODOSTOMIA FASCIATA** DKK.

Pl. I. Fig. 43.

TRYON, Man. Conch., VIII., p. 364.—DUNKER, Moll. Jap., p. 17.—

PILSBRY, Cat. Mar. Moll. Japan, p. 84.

Shinagawa (rare).

Living at Nagasaki.

55. **ODOSOMIA PLANATA** GLD.

BRAUNS, Geol. Env. Tokio, p. 32.—GOULD, Otia Conch., p. 148.

Ōji (very abundant).

Living at Hong-kong.

56. **ODOSTOMIA** *CFR. SUBPLANATA* GLD.

Pl. I. Fig. 44.

BRAUNS, *Geol. Env. Tōkio*, p. 32.—GÖULD, *Onia Conch.*, p. 148.

Ōji (rare).

57. **ODOSTOMIA TAKINOGAWENSIS** TOK.

Pl. I. Fig. 45.

Shell tubulated; whorls six, longitudinally ribbed, partly smooth in the body-whorl, flattened a little on the upper side; suture distinct; aperture oval; inner lip thickened. Height 45^{mm}; breadth 2^{mm}.

Ōji (rare).

PYRAMIDELLIDÆ.

58. **PYRAMIDELLA EXIMIA** LISCHKE.

Pl. I. Fig. 46.

LISCHKE, *Jap. Meeres-Conch.*, III., p. 59.—PILSBRY, *Cat. Mar. Moll. Japan*, p. 29.

Ōji (rare).

Living at Tōkyō and Kamakura (Sagami).

59. **PYRAMIDELLA SPIRATA** A. AD.

Pl. I. Fig. 47.

TRYON, *Man. Conch.*, VIII., p. 297.—PILSBRY, *Cat. Mar. Moll. Japan*, p. 79.

Tabata (rare).

Living: Ōshima (Izu) and Philippines.

60. **PYRAMIDELLA CINCTELLA** A. AD.

Pl. I. Fig. 48.

TRYON, Man. Conch., VIII., p. 307.—PILSBRY, Cat. Mar. Moll. Japan, p. 79.

Ōji and Tabata (rare).

Living: Tōkyō, Enoshima (Sagami), Setouchi (Inland Sea), and Ōshima (Izu).

CERITHIIDÆ.

61. **CERITHIUM KOCHII** PHIL.

Pl. I. Figs. 49 *a* and *b*.

PHILIPPI, Abbild. and Besch. &c., III., p. 14.—TRYON, Man. Conch., IX., p. 147.—PILSBRY, Cat. Mar. Moll. Japan, p. 56.

Shinagawa (rare).

Living: Misaki (Sagami), Yokosuka, Banda (Awa or Bōshu), Kominato (Awa or Bōshu), Katanoura (Kii), Tango, Nagasaki, China, Port Jackson, Van Dieman's Is., E. Coast of Africa.

62. **CERITHIUM NIPPORIENSIS** TOK.

Pl. I. Fig. 50.

Shell subulate, small; whorls eight, flat, ornamented with a few, distinct, continuous longitudinal ribs, and three transverse bands in each whorl except the last, which also cross the ribs and project as granules; body-whorl distinctly angulated on periphery, the lower part devoid of longitudinal ribs and tra-

versed by narrow but distinct striations; aperture subquadrate; outer lips curved; canal pointed below. Height and breadth 15^{mm} and 6^{mm}; or 8.5^{mm} and 3.8^{mm}.

Tabata (rare).

63. **CERITHIUM (CERITHOPSIS) TABATENSIS** TOK.

Pl. I. Fig. 51.

Shell elongate-turreted, thick, many-whorled; spire subulate and elevated; volution flat, ornamented with three equally granulated bands and indistinct irregular varices; lower half of body-whorl smooth; aperture oval, narrowed below; inner lip thickened. Height 6^{mm} and breadth 1.5^{mm}.

Tabata (rare).

64. **POTAMIDES (LAMPANIA) ZONALE** BRUG.

LISCHE, Jap. Meeres-Conch., I., p. 73, and II., p. 69.—TRYON, Man. Moll., IX., p. 118 and p. 167.—BRAUNS, Geol. Env. Tōkio, p. 52.—PILSBRY, Cat. Mar. Moll. Japan, p. 57.

Ōji (rare), Tabata (abundant).

Living: Tōkyō, Yokohama, Hakodate, Matsushima (Rikuzen), Tsu (Ise), Nagasaki, Ōshima (Izu), Tosa and Hong-kong.

65. **POTAMIDES (TYMPANOTONOS) FLUVIATILIS**

POTIEZ and MICH.

Pl. I. Fig. 52.

TRYON, Man. Conch., IX., p. 159.—PILSBRY, Cat. Mar. Moll. Japan, p. 57.—LISCHE, Jap. Meeres-Conch., II., p. 69.

Synonym:—*P. micropterus* KLENER.—*P. alatus* PHIL.—*P. radix* DURO.—*P. retifera* A. AD.—*P. euryptera* A. AD.

Shinagawa (rare), Tabata (frequent).

Living: Tōkyō Bay, Nagasaki, Ise, Bonin Is., China, Hong-kong, Philippines, Shingapore, Borneo, Australia, Mergui Is. and India.

66. **POTAMIDES** CFR. **INCISUS** HOMBR. and JACQ.

Pl. I. Fig. 53.

TRYON, Man. Conch., IX., p. 160.

Tabata (frequent).

Living *P. incisus* HOMBR. and JACQ. was collected in the Philippines.

RISSOIDÆ.

67. **RISSOA (FENELLA)** CFR. **CERITHINA** PHIL.

Pl. I. Fig. 54.

TRYON, Man. Conch., IX., p. 395.—ANN. Mag. Nat. Hist., VI. 1860, p. 421.

Synonym:—*F. reticulata* A. AD.—*F. scabra* A. AD.

Tabata (frequent).

Living specimens of *R. cerithina* PHIL. were collected in Japan, Red Sea, Persian Gulf and Rodriguez Is. (in Indian Ocean).

68. **RISSOA SEPTENTRIONALIS** TOK.

Pl. I. Fig. 55.

Shell turreted; whorls seven, granulate at the intersections of the longitudinal and spiral ribs as in the preceding species, but the transverse liræ are not interrupted even upon the longitudinal costæ; both ribs are also narrower than in the preceding form and retain almost equal width throughout the whole spire. Height and breadth 4^{mm} and 1.5^{mm}; or 3.8^{mm} and 1.5^{mm}.

Tabata (frequent).

69. *RISSOA MERIDIONALIS* TOK.

Pl. I. Fig. 56.

Shell turreted; whorls nine, angulated, each ornamented with two or three large transverse elevated ridges, decussated by longitudinal ribs; body-whorl angulated at the periphery, the lower part of which is only spirally striated; aperture subcircular; outer lip not thickened, and without denticulation. Height 4^{mm} and breadth 1.8^{mm}.

Shinagawa (rare).

70. *RISSOA SUBCYLINDRICA* TOK.

Pl. I. Fig. 57.

Shell small, elongate, subcylindrical, with obtuse apex; whorls five, convex, finely transversely striated; suture deep; aperture ovate, rather narrow at the upper part; inner lip thickened. Height 32^{mm} and breadth 1.7^{mm}.

Tabata (rare).

Order Scutibranchiata.

ROTELLIDÆ.

71. *ROTELLA COSTATA* LESSON, VAR. *SUPERBUS* GLD.

Pl. I. Fig. 58.

BRAUNS, Geol. Env. Tōkio, p. 52.—PILSBRY, Cat. Mar. Moll. Japan, p. 100.—LISCHKE, Jap. Meeres-Conch., II., p. 83.—GOULD, Otia Conch., p. 156.

The color of the shell is very variable. It is preserved in my specimen in numerous bands of a brownish tint somewhat

radially arranged, each one being placed between the striations of the whorl. In the base somewhat long brownish spots are found but only in the circumscribed region near the outer margin, the rest being uniformly cherry coloured without spots.

Shinagawa and Tabata (rare).

Living: Enoshima (Sagami), Awa or Bōshu, Shimoda (Izu), Hakodate, Shima, Futamigaura (Ise), Nagato, Katanoura (Kii), Mogi (Hizen), Tsushima and Nagasaki.

TURBINIDÆ.

72. TURBO GRANULATUS GMEL.

Pl. I. Fig. 59.

TRYON, Man. Conch., X., p. 217.—PILSBRY, Cat. Mar. Moll. Japan, p. 88.—MORSE, Shell-Mound of Ōmori, p. 67.—LISCHKE, Jap. Meeres-Conch., II., p. 81.—Syst. Conch. Cab., II. 3, p. 37.

Synonym:—*T. modestus* PHIL.—*T. coreensis* RECL.—*T. granulatus* SOW.

Tabata (very rare).

Found in the shell mounds of the Stone-age at Ōmori.

Living: Enoshima (Sagami), Ise, Okayama, Kōchi (Tosa), Nagasaki, Kii, Shima, China Sea and Nicobar (Indian Ocean).

TROCHIDÆ.

73. TROCHUS IMPERIALIS A. AD.

Pl. I. Fig. 60.

LISCHKE, Jap. Meeres-Conch., III., p. 67.—PILSBRY, Cat. Mar. Moll. Japan, p. 92.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 358.

Synonym:—*T. adamsianus* SCHRENCK.

Shinagawa (rare).

Living: Tōkyo, Hakodate, and Sumoto (Awaji).

74. **TROCHUS ARGYROSTOMUS** Gmel.

Pl. II. Fig. 1.

BRAUNS, Geol. Env. Tōkio, p. 34.—LISCHE, Jap. Meeres-Conch., I., p. 96.—SYST. Conch. Cab., II. 3, p. 25.

Ōji (rare).

Living: Tōkyō, Hakodate, Kii, China, Port Hamilton (southern coast of Corea), Posjet Bay, Formosa and Philippines.

75. **TROCHUS AMUSSITATUS** GLD.

Pl. II. Fig. 2.

TRYON, Man. Conch., X., p. 188, and p. 250.—Ann. Mag. Nat. Hist., 1875, XVI., p. 109.

Shinagawa (very rare).

Living at Yamada and Endermo.

76. **TROCHUS (EXIDA) JAPONICUS** A. AD.

Pl. II. Fig. 3.

DUNKER, Index Moll. Maris Jap., p. 130.

Shinagawa (rare).

Living at Misaki (Sagami) and Minoshima (Kii).

77. **TROCHUS (CALLIOSTOMA) SHINAGAWENSIS** TOK.

Pl. II. Fig. 4.

Shell imperforate. Spire elevated, acute with flat whorls. Whorls strongly sculptured on upper portion with granulated spiral ribs narrower than the interspaces, numbering two to four on each whorl; base nearly flat, coarsely but equally ribbed;

no longitudinal striæ. Height and breadth 17.5^{mm} and 16^{mm} — 19^{mm} , or 14^{mm} and 13^{mm} — 14^{mm} , or 7.5^{mm} and 8^{mm} — 9^{mm} .

This tolerably large form is not found living in Japan. In the deposits of Shinagawa, it is quite abundant.

78. **TROCHUS (MINOLIA) ANGULATUS** TOK.

Pl. II. Fig. 5.

Shell flatly conical, small, thin, distinctly angulated at the periphery; whorls five, quite smooth, ornamented with two transverse rows of crimson dots in the periphery and one row of larger dots of violet near the suture line; aperture angular; umbilicus wide, with many fine transverse ridges within. Similar in shape to *M. pulcherrima* ANGAS or *M. philippensis* WATSON of the Philippines. Height 4^{mm} and breadth 4^{mm} .

Ōji (rare).

FISSURELLIDÆ.

79. **FISSURELLA (MACROCHISMA) LISCHKEI** PILSBRY.

Pl. II. Fig. 6.

PILSBRY, Cat. Mar. Moll. Japan, p. 106.

Shinagawa (rare).

Living at Enoshima (Sagami), and Nemoto (Awa or Bōshu).

80. **ACMAEA CONULUS** DKK.

Pl. II. Figs. 7 *a* and *b*.

DUNKER, Moll. Jap., XIII., p. 45.—LISCHEKE, Jap. Meeres-Conch., II., p. 96.—PILSBRY, Cat. Mar. Moll. Japan, p. 110.

Tabata (rare).

Living: Tōkyō, Yokohama, Enoshima (Sagami) and Nagasaki.

PATELLIDÆ.81. **PATELLA (HELCONISCUS) AMUSSTATATA** RVE.

Pl. II. Fig. 8.

TRYON, Man. Conch., XIII., p. 134.—LISCHE, Jap. Meeres-Conch., II., p. 100.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 300.

Synonym:—*P. granostriata* RVE.

Tabata (rare).

Living: Hakodate, Kachiyama (Awa or Bōshu), Atami (Izu), Futamigaura (Ise), Kii, Fukushimaura (Tosa), Kōchi (Tosa), Bonin Island, China, and Philippines.

Gastropoda-Opisthobranchiata.**Order Tectibranchiata.****TORNATELLIDÆ.**82. **TORNATINA EXILIS** DKR.

Pl. II. Fig. 9.

BRAUNS, Geol. Env. Tōkio., p. 34.—DUNKER, Moll. Jap. p. 25.

Ōji and Tabata (rare).

Living at Nagasaki.

83. **TORNATELLA GIGANTEA** DKR.

Pl. II. Fig. 10.

DUNKER, Index. Moll. Mar. Jap.

Shinagawa and Ōji (rare).

Living in Japan.

84. **RINGICULA ARCTATA** GLD.

Pl. II. Fig. 11.

BRAUNS, Geol. Env. Tōkio, p. 30.—LISCHE, Jap. Meeres-Conch., II., p. 78.—GOULD, Ofia Conch., p. 122.—PILSBRY, Cat. Mar. Moll. Japan, p. 10.

Ōji, Shinagawa and Tabata (very abundant).

Living: Tōkyō, Nagasaki and Hong-kong.

CYLICHNIDÆ.85. **CYLICHNA MUSASHIENSIS** TOK.

Pl. II. Fig. 12.

BRAUNS, Geol. Env. Tōkio, p. 35.—WOOD, Crag Moll., I., 175.

Shell cylindrical, convolute, entirely smooth; vertex depressed, concave, with a hidden spire; aperture linear, dilated at the base, with an obtuse fold upon the columella. Height and breadth 17^{mm} and 7^{mm}; or 19^{mm} and 7.5^{mm}; or 7^{mm} and 3^{mm}.

BRAUNS identified this species with *Bulla cylindracea* PENNANT. of the Crag and the British Seas, but it is easily distinguished from it by having a more elongated shell, no transverse striations on the surface, and by the narrower dilatation at the base of the aperture.

Shinagawa, Ōji and Tabata (rare).

86. **CYLICHNA ACUTA** TOK.

Pl. II. Fig. 13.

Shell small, thin, subfusiform, convolute; spire hidden, outer lip elevated and so elongated at the upper part as to give it the appearance of having an acuminate apex, rounded at the lower part; surface smooth; aperture linear, expanded below with an obsolete fold upon the columella. Height 5^{mm} and breadth 2^{mm}.

Ōji (frequent).

87. **CYCLINA OBTUSA** TOK.

Pl. II. Fig. 14.

Shell small, cylindrical, thin, convolute; spire almost hidden, appearing as if pushed in from above, and terminating in a small blunt point; surface transversely striated, the striæ being fine and close together; aperture as long as the shell, narrow, widened and truncated at the base; columella with two oblique plaits at its base. Height 4^{mm}; breadth 2^{mm}.

Tabata (rare).

Scaphopoda.**DENTALIIDÆ.**88. **DENTALIUM OCTOGONUM** LAMK.Pl. II. Figs. 15 *a* and *b*.

LISCHE, Jap. Meeres-Conch., II., p. 103 and III., p. 75.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres., p. 381.—BRAUNS, Geol. Env. Tōkio, p. 35.

Shinagawa and Ōji (rare).

Living: Tōkyō, Hakodate, Enoshima (Sagami), Kii, Nagasaki, China and Ceylon.

89. **DENTALIUM** CFR. **WEINKAUFFI** DKR.Pl. II. Figs. 16 *a* and *b*.

DUNKER, Index. Moll. Maris. Jap., p. 153.—TRYON and PILSBRY, Man. Conch., XVII., p. 40.

Shell large, solid, the posterior third more curved than the remaining portion, not compressed between convex and concave

side, rounded in cross-section; the length about ten to eleven times the diameter of the aperture. Longitudinal ribs prominent near the apex, gradually decreasing in size towards the posterior, so that they are obsolete on the anterior third of the shell. At apex there are eight to eleven rather sharp and well raised ribs, separated by wider concave intervals; at a short distance from the apex, an interstitial riblet appears in these intervals, so that the ribs and the riblets alternate each other; in larger specimens there is a still smaller thread between the rib and the riblet. Circular sculpture not conspicuously developed. Apex with a v-shaped notch at the convex side. Length 55–80^{mm}.

On consulting the descriptions and figures given by DUNKER and PILSBRY, this species is closely allied to *Dentalium (Antalis) weinkauffi* DKR., but in fossil specimens the ribbed portion is not so distinctly separated from the smooth portion as shown in the figure of the living specimens. Moreover, the number of ribs at the apex is greater in the living than in the fossil one. One fragmentary living specimen collected in Asamiwan, province of Tsushima, and another one said to have been collected at an unknown place in Japan probably belong to the same species. The question whether the fossil form is really identical with *Dentalium weinkauffi* DKR. can only be settled by comparing a still greater number of specimens both living and fossil. The fossil has been taken by BRAUNS for *Dentalium entale* LINNÉ. Shinagawa (abundant).

90. *DENTALIUM EDOENSIS* TOK.

Pl. II. Fig. 17.

Shell small, curved, very slender and tapering, thin and fragile, slightly swollen close to the aperture; surface glossary,

entirely devoid of longitudinal and transverse striations, sometimes with a few annular swellings. Apex with simple orifice, no slit; aperture as well as apical orifice circular. Length 25^{mm} in the largest specimen, and fourteen to sixteen times the greatest diameter.

Shinagawa and Ōji (rare).

The living specimens were collected near Enoshima and Nagasaki.

Pelecypoda.

Order Siphonida.

PHOLADIDÆ.

91. MARTESIA STRIATA LINNÉ.

Pl. II. Fig. 18.

DUNKER, Index Moll. Maris Jap.,—Chall. Report, Vol. XIII, p. 19 and 27.—TRYON, Struct. and Syst. Conch., III., p. 128.

Synonym.—*Pholas pusilla* LINNÉ.

In the drift woods found in the bluish clay of Tabata (frequent).

Living chiefly in the floating woods and found in Japan, Philippines, West Indies, German Ocean, Mediterranean Sea, Antillus, Central America, etc.

SOLENIDÆ.

92. SOLEX GOULDII CONRAD.

DUNKER, Index Moll. Maris Jap., p. 173.—LISCHE, Jap. Meeres-Conch., II., p. 123.—GOULD, Otia Conch., p. 165.—Syst. Conch. Cab., XI. 3, p. 21.—BRAUNS, Geol. Env. Tōkio, p. 36.

Synonym.—*S. gracilis* GLD.

Ōji (rare).

Living: Enoshima (Sagami), Misaki (Sagami), Hakodate, Ise, Nagasaki and China Sea.

93. **SOLEX KRUSENSTERNII** SCHRENCK.

Pl. II. Fig. 19.

SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres., p. 594.—BRAUNS, Geol. Env. Tōkio, p. 36.

Ōji (abundant), Tabata and Shinagawa (frequent).

Living: Hakodate, Kuriles, East Coast of Sakhalin and Akashi Bay.

94. **MACHA DIVARICATA** LKE.

Pl. II. Figs. 20 *a* and *b*.

LISCHE, Jap. Meeres-Conch., I., p. 142.—PILSBRY, Cat. Mar. Moll. Japan, p. 121.—Syst. Conch. Cab., XI. 3, p. 87.

Shinagawa (frequent).

Living: Enoshima (Sagami), Misaki (Sagami), Hakodate, Wakanoura (Kii), Nagasaki, and Setouchi (Inland Sea).

SAXICAVIDÆ.

95. **SAXICAVA ARCTICA** DESH.

Pl. II. Figs. 21 *a* and *b*.

WOOD, Crag. Moll., II., p. 287.—DESHAYES, Traité élém. Conch., p. 480.—WEINKAUFFE, Conch. Mittelmeeres, II.—Ann. Mag. Nat. Hist., IV. 20, (1877), p. 131.—Trans. Royal Soc. South Australia.—Verh. Russ.-kais. Mu. Gesell. zu St. Petersburg, II series, XXX-VIII Band, 1, 1900.—Chall. Report, Vol. XIII., p. 78.—TRYON, Struc. and Syst. Conch., II., p. 135.—KOEBELT, Conchylien-buch,

p. 318.—LISCHE, Jap. Meeres-Conch., I., p. 134, and III., p. 100.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 553.—PILSBRY, Cat. Mar. Moll. Japan, p. 117.—GORD, Otia Conch., p. 163.

Synonym:—*S. lithophagella* DA COSTA; *S. elongata* BRONN; *S. rhomboides* POLA; *S. minutes* LINNÉ; *S. praeisus* MONTAGU; *Mytilus rugosa* LINNÉ; *M. pholadis* LINNÉ.

In the determination of this species the form of the shell, the inequilateral state of the valves, and the imbrication on the siphonal side can not be availed of; for, on comparing my specimens with the figure in WOOD's "*Crag Mollusca*," I find that in WOOD's specimen the outer imbricating ridge (not imbrication), runs not along the posterior edge of the shell as in my specimens, but leaves broad spaces between it and the posterior edge; also the surface of the shell in the English form is furnished with many elevations and depressions. Some specimens from the Grand Banks in Newfoundland and from Great Britain, which are preserved in our Science College, are furnished not with ridges, but only with great elevations not so strongly curved as in my specimens.

Tabata (abundant).

Miocene—Vienna (Vörsan, Garifahren, Enzesfeld, Pötzleinsdorf, Grund, Grinzing, Steinbrun), Turin.

Pliocene—Asti, Castel Anquinto, Messina, Belgium, Crag of England (Cor. Crag—Sutton, Red Crag—Sutton, Walton Naze, Cleyde Beds, Brindlington).

Younger Tertiary—Sicily, Rhodus, Ischia, Puzzabli, Christiana, Scandinavia, Australia.

Diluvium—England, Canada, Sweden, Russia (Murman and White Seas, and Nova Zembla).

World wide in Recent time:

Fukagawa and Susaki (Tōkyō), Misaki (Sagami), Nanao

(Noto), Nemoto, Shirahama and Kominato (Awa or Bōshu), Ōsaka, Hakodate.

East Coast of Northern Asia—Kamtschatka, Ochotschk Sea, Avikamch Is., Behring Sea, Awatka Bay, Castries Bay, White Sea.

North Coast of Asia—Siberia.

West Coast of America—Sitka, Puget-Sund, Vancouver Is., San Francisco, Monterey, Sta. Barbara, S. Diego, Mangarita Bay, Cape St. Lucas, Mazatlan, Acapulco, Peru, St. Elena, West Patagonia.

East Coast of America—Champlain Sea, Prince Edward Is., Newfoundland, Massachusettes, Mosse-a-bee Beach (Maine) &c.

Europe—Great Britain, Christiania (Norway), Sicily, Modena (Italy), Rudelsdorf (Bavaria), Scandinavia, Azopes, Mediterranean Sea, Nova Zembla, &c.

Africa—off Cape of Good Hope, West African Coast, &c.

Indian Ocean—Madagascar, &c.

Australia (Port Jackson) and New Zealand, &c.

96. *PANOPEA GENEROSA* GLD.

BRAUNS, Geol. Env. Tōkio, p. 36.—GOULD, Otia Couch., p. 165.—DUNKER, Index Moll. Maris Jap., p. 176.—Geol. Surv. California-Paleont. II.—ARNOLD, Pal. and Str. Mar. Pliocene and Pleistocene San Pedro (Mem. Cal. Acad. Sc., Vol. III., 1903).

Ōji and Shinagawa (frequent).

Miocene—Oregon, Martinez, Walnut Creek, near Mt. Diablo, Estrella, Foxinis; (California).

Pliocene—San Ferdinando, San Pedro, Santa Barbara; (California).

Diluvium—Santa Barbara, San Pedro; (California).

Living: Hakodate, Awatcha Bay (Kamtschatka) and Puget Sound (Oregon).

CORBULIDÆ.**97. CORBURA VENUSTA** GLD.Pl. II. Figs. 22 *a*, *a'*, *b* and *b'*.

SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres., p. 583.—GOULD, Otia Conch., p. 164.

Shinagawa (frequent), Ōji (rare).

Living at Hakodate and Whampoa (near Canton).

98. NEERA GOULDIANA HINDS.Pl. II. Figs. 23 *a* and *b*.

KOEBELT, Illustr. Conch.

Shinagawa (very rare).

Living: Uraga (Sagami), Gotō Is. and Tsushima.

ANATINIDÆ.**99. MYODORA FLUCTUOSA** GLD.Pl. II. Figs. 24 *a* and *b*.

GOULD, Otia Conch., p. 161.—BRAUNS, Geol. Env. Tōkio, p. 37.

Synonym.—*M. proxima* SMITH.

Shinagawa and Ōji (frequent).

Living in Kagoshima Bay.

MACTRIDÆ.**100. MACTRA SACHALINENSIS** SCHRENCK.Pl. II. Figs. 25 *a* and *b*.

SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres., p. 515.—Syst. Conch. Cab., XI. 2, p. 67.

Synonym.—*M. lühdorffi* DKR.

What BRAUNS designated by the name of *M. sachalinensis* SCHRENCK is *M. sulcataria* DESH., as I am now fully convinced.

Ōji (rare).

Living: Kujūkurihama (Shimōsa), Hakodate, Otaru (Hokkaidō), Dui Choji and Wjatchu (West Coast of Sakhalin), Kaisenhafen and Castries Bay (Mandschurian Coast of North Japanese Sea).

This species which is conspicuous for its large shell appears to have its southern limit at Chōshi (Shimōsa).

101. *MACTRA VENERIFORMIS* DESH.

BRAUNS, Geol. Env. Tōkio, p. 38.—LISCHE, Jap. Meeres-Conch., I., p. 153, and II., p. 121.—MORSE, Shell-mound of Ōmori, p. 58.—Syst. Conch. Cab., XI., 3, p. 63.

Synonym.—*M. quadrangularis* DESH.

Ōji (frequent), Shinagawa (rare).

Living: Ōmori (in Tōkyō Bay), Kii, Higo, Nagasaki, Kagoshima, Tschifu, North China.

102. *MACTRA SULCATARIA* DESH.

Pl. II. Figs. 26 *a* and *b*.

LISCHE, Jap. Meeres-Conch., I., p. 133.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 570.—BRAUNS, Geol. Env. Tōkio, p. 28.

Ōji (abundant), Shinagawa (rare).

Living: Tōkyō, Enoura (Suruga), Izumi, Kōchi (Tosa), Nagasaki, Kagoshima, Hakodate, North China, Possjet Bay, Kurile Sea at the east coast of Sakhalin.

103. *MACTRA CROSSEI* DKK.Pl. II. Figs. 27 *a* and *b*.

DUNKER, Index Moll. Maris Jap., p. 183.

Ōji (rare).

Living: Tōkyō, Kominato (Awa or Bōshu), Sagami and Kii.

104. *LUTRARIA OVALIS* TOK.Pl. II. Figs. 28 *a*, *b* and *c*.

Shell oblong, thick, compressed, subequilateral; the curvature very different in the anterior and posterior sides; surface sculptured with fine concentric striations; umbones exceedingly anterior in situation.

Length	90 ^{mm} ,	88 ^{mm} ,	83 ^{mm}
Height	47 ^{mm} ,	47 ^{mm} ,	43 ^{mm}
Breadth	28 ^{mm} ,	24 ^{mm} ,	24 ^{mm}

My specimens greatly resemble to the European species *Lutrarica oblonga* LAM., but the curvature of the upper margin, and also of the anterior and posterior ends is somewhat different.

Shinagawa (rare).

Living: Ajiro (Izu), Hyōgo (Settsu) and Kōchi (Tosa).

105. *TRESUS* SP.Pl. II. Figs. 29 *a*, *b* and *b'*.

Shell small, oblong; umbilicus nearly at the centre of upper margin; very low ridge running from the umbilicus to the postero-ventral edge; pallial sinus deep. Length 25^{mm}, height 16.5^{mm}, and breadth 10^{mm}.

This specimen may be perhaps the young of *Tresus nuttali* CONRAD, but compared with the adult shell of *Tresus nuttali* CONRAD the posterior side is not truncated and more elongated. The four living species of Japanese *Lutraria* are not identical with the present species.

Ōji (rare).

106. TRESUS NUTTALI CONRAD.

BRAUNS, Geol. Env. Tōkio, p. 38.—MIDDENDORF, Mal. Ross., III, p. 66.—MORSE, Shell-Mound of Ōmori, p. 61.—GOULD, Otia Conch., p. 76.—LISCHKE, Jap. Meeres-Conch., I, p. 136.—Geol. Surv. California-Palæont. II.—ARNOLD, Pal. and Str. Mar. Pliocene and Pleistocene. San Pedro, (Mem. Cal. Acad. Sc., Vol. III., 1903).

Synonym.—*Lutraria maxima* MIDD.; *L. capax* GOULD.

Ōji (abundant), Shinagawa (rare).

Pliocene—Santa Barbara (California).

Diluvium—Santa Barbara, San Diego, San Pedro, (California).

Living: Tōkyō, Yokohama, Hokodate, Sitcha, along west coast of America from 34° N. to 58° N. (Vancouver Is., Fuscastrasse, Puget sound, San Francisco, Montari, Sta Barbara, S. Pedro, S. Diego).

TELLINIDÆ.

107. TELLINA NITIDULA DKR.

Pl. II. Figs. 30 *a*, *a'*, and *b'*.

BRAUNS, Geol. Env. Tōkio, p. 39.—LISCHKE, Jap. Meeres-Conch., I, p. 129, and II, p. 113.—Syst. Conch. Cab., X. 4, p. 161.

Shinagawa and Ōji (frequent).

Living: Misaki (Sagami) and Kii.

108. **TELLINA YEDOENSIS** LISCHKE.Pl. II. Figs. 31 *a* and *a'*.

BRAUNS, Geol. Env. Tōkio, p. 39.—LISCHE, Jap. Meeres-Conch., II., p. 92.

Oji and Tabata (frequent), Shinagawa (rare).

Living: Tōkyō and Kii.

109. **TELLINA SERRICOSTATA** TOK.Pl. II. Figs. 32 *a*, *a'* and *b*.

Shell ovate, solid, equilateral, flattened; anterior margin rounded, posterior pointed, with the surface near it abruptly concave, and either somewhat undulatory or irregularly ribbed; concentric ribs very strong, serrated and dense, especially in the posterior portion of the shell; lunule small and lanceolate; two median and two lateral teeth in each valve; mantle impression deep. This species resembles *Tellina serrata* BROCCHI, but the thickness of the shell and the form of the postero-dorsal margin of the inner surface distinguish these two species.

Length	34 ^{mm} ,	25 ^{mm} ,	25 ^{mm}
Height	24 ^{mm} ,	17 ^{mm} ,	15 ^{mm}
Breadth	10 ^{mm} ,	8 ^{mm} ,	9 ^{mm} .

Shinagawa and Tabata (rare).

110. **TELLINA TENERA** SAY.Pl. II. Figs. 33 *a* and *a'*.

Syst. Conch. Cab., X. 4, p. 152.

Ōji and Shinagawa (rare).

Living along the Northern Atlantic Coast of North America (from Cape Anu to New York and Massachusetts).

111. **TELLINA OJIENSIS** TOK.Pl. II. Figs. 34 *a*, *a'* and *b*.

Shell thick, tolerably swollen in the right valve; anterior side uniformly rounded; posterior shortened and not so abruptly truncate as in many other species, but with a only slightly depression running from the umbonal region to near the postero-ventral angle; ventral margin, uniformly rounded; whole surface with densely numerous, regularly arranged, strong ribs; pallial sinus very large; hinge with a bifid cardinal tooth and a strong lateral tooth on each side. Length 22^{mm} (or 20^{mm}); height 18^{mm} (or 15^{mm}); and breadth 10^{mm} (or 8^{mm}).

Ōji (rare).

Living at Hakodate.

112. **TELLINA** AFF. **RUTILE** DKK.Pl. II. Figs. 35 *a* and *a'*.

DUNKER, Index Moll. Maris Jap., p. 191.—PILSBRY, Cat. Mar. Moll. Jap., p. 124.

Ōji and Shinagawa (rare).

T. rutile DKK. is found living near Enoshima (Sagami) and Nagasaki.

113. **TELLINA NIPPONICA** TOK.Pl. II. Figs. 36 *a* and *a'*.

Shell transversely ovate, compressed, inequilateral; anterior side rounded, posterior short and subrostrated; surface with fine concentric striations; cardinal tooth bifid in both valves; one indistinct lateral tooth present. Length 21^{mm}; height 15^{mm}; and breadth 9^{mm}.

Ōji (rare).

Living: Tōkyō, Yokohama and Nagasaki.

114. **GARI** CFR. **RADIATA** DKR.

Pl. III. Figs. 1 *a*, *a'*, *a''* and *b*.

PHILIPPI, Abbild. and Besch. &c., I.

Synonym.—*Psammobia amethystus* RVE.

Shinagawa (rare).

Living specimens are found near Misaki (Sagami).

115. **MACOMA NASUTA** CONRAD.

Pl. III. Figs. 2 *a* and *b*.

BRAUNS, Geol. Env. Tōkyō, p. 39.—LISCHE, Jap. Meeres-Conch., II., p. 115.—GOULD, Otia Conch., p. 188.—MIDDENDORF, Mal. Ross., p. 61.—MIDDENDORF, Sib. Reise., p. 256.—Ann. Mag. Nat. Hist., III. 16. (1865).—Syst. Conch. Cab., X. 4, p. 229.—Geol. Surv. California-Palæont. II.—ARNOLD, Pal. and Str. Mar. Pliocene and Pleistocene San Pedro (Mem. Cal. Acad. Sc., Vol. III., 1903).

Synonym.—*Tellina tersa* GLD.; *T. dissimilis* MARTENS.

Ōji (abundant), Tabata (frequent), Shinagawa (rare).

Upper Miocene—Foxins (California).

Pliocene—San Fernando, Santa Rosa; (California).

Diluvium—San Pedro (California).

Living: Hakodate, Eehigo, Tōkyō, Misaki (Sagami) Kamtschatka, Behring Sea, Sitcha, South Coast of Ochotsk-Bay, Esquimalt Harbour, West Coast of North America from the Northern limit (Vancouver, Oregon, Monterey, S. Diego).

PETRICOLIDÆ.

116. **SAXIDOMUS NUTTALLI** CONRAD.

BRAUNS, Geol. Env. Tōkyō, p. 40.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 253.—LISCHE, Jap. Meeres-Conch. I., p. 127.—

DUNKER, Index. Moll. Maris Jap., p. 208.—Syst. Conch. Cab., XI. 1, p. 242.—TRYON, Struc. and Syst. Conch., p. 175.—Geol. Surv. California-Paleont. II.

Synonym:—*Venus sulcata* POT. and MICH.; *Venurupis gigantea* DESHAYES; *Venus maxima* ANTON; *Saxidomus squalidus* DESHAYES; *S. purpuratus* DESHAYES.

Ōji (abundant), Shinagawa (rare).

Diluvium—Santa Barbara and San Pedro (California).

Living: Tōkyō, Misaki (Sagami), Ōtsu (Sagami), Enoshima (Sagami), Hakodate, Akashi (Harima), Setouchi (Inland Sea), Chichijima (Bonin Is.), Kamtschatka, Sitcha, San Diego (California), Kuraché (Mouth of the Indus, India), Copisco (Chile).

VENERIDÆ.

117. VENUS STIMPSONI GLD.

BRAUNS, Geol. Env. Tōkio, p. 48.—COULD, Otia Conch., p. 169.

Ōji (frequent), Shinagawa (rare).

Living at Hakodate and Etorofu (Chishima).

118. VENUS FOLIACEA PH.

Pl. III. Figs. 3 *a* and *b*.

PHILIPPI, Abbild. and Besch. &c., II., p. 107.—Chall Report.

Shinagawa (frequent).

Living: Tōkyō, Enoshima (Sagami), Katanoura, Torres Strait, North Australia, Port Curtis, Queensland, Ceylon, Red Sea, and Madagascar.

119. CYTHEREA CHINENSIS CHEM.

Pl. III. Figs. 4 *a* and *b*.

LISCHE, Jap. Meeres-Conch., p. 122.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres., p. 541.—Syst. Conch. Cab., XI. 1, p. 31.

Synonym:—*C. pacifica* DILL.; *C. sinensis* Sow.

Shinagawa (frequent).

Living: Sagami, Kii, Nagasaki, Hakodate, Kitami (Hokkaidō), West and East Coast of Sakhalin, China, New-Holland, Dui and Ssakato (Tartary Strait), and Castries Bay.

120. CYTHEREA MERETRIX LINNÉ.

Pl. III. Figs. 5 *a* and *b*.

BRAUNS, Geol. Env. Tōkio, p. 53.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 545.—LISCHEKE, Jap. Meeres-Conch., I., p. 122 and II., p. 108.—MORSE, Shell-Mound of Ōmori, p. 59.—DUNKER, Moll. Jap., p. 26.—PHILIPPI, Abbild. and Besch. &c.—Syst. Conch. Cab., XI. 1, p. 15.

Synonym:—*Venus lisoria* CHEM.; *Cytherea fusca* ROCII.; *C. formosa* SOW.; *C. petachalis* LAM.; *C. impudica* LAM.; *C. castanea* LINNÉ.; *C. zonaria* LAM.; *C. graphica* LAM.; *C. morphina* LAM.; *C. ponderosa* SCHUM.

Shinagawa (rare).

Living: Tōkyō, Enoshima (Sagami), Chōshi (Shimōsa), Tsuda (Awa), Misaki (Sagami), Yokohama, Kuwana (Ise), Gōnoura (Iki), Kagoshima, Higo, Fushiki (Noto), Hakodate, Naruto (Awa), Nagasaki, Riu-Kiu, Formosa, E. Indies, Canton River, Chi-fu, Hongkong, Siam, Philippines, Singapore, Amboina, Ceram, Tenimber Is. (in Banda Sea), Molucca, Nicobar, Ceylon, Mazatlan, Shanghai, Labuan (Borneo) and Java.

121. DOSINIA EXOLETA LINNÉ

BRAUNS, Geol. Env. Tōkio, p. 41.—RÖMER, Monogr. Venus.—LISCHEKE, Jap. Meeres-Conch., I., p. 127.—Weinkauff, Conch. Mittel-Meer, I., p. 120.—MORSE, Shell-Mound of Ōmori, p. 57.—Hörner, Tertiär-becken Wien, II., p. 143.—Syst. Conch. Cab., XI. 1, p. 90.

Synonym:—*D. japonica* RVE.; *D. troscheli* LKE; *Pectunculus capillaceus* DA COSTA; *Cytherea sinuata* TURTON; *Exoleta orbicularis* BROWN; *Artemis lentiformis* WOOD.

Ōji (very abundant), Shinagawa (frequent).

Miocene—Vienna, Schneitzenland, Touranie.

Pliocene—Crag of England and Belgium, Sub-appennine, Castel Arquanto, Asti, Rome, Livorino, Sicily.

Younger Tertiary—Calabria, Tarents, Sicily.

Diluvium—Palermo, Morea, Cyperu, Rhodus, Glacial bed of England.

Living: Tōkyō, Shimōsa, Hakodate, Enoshima (Sagami), Misaki (Sagami), Enoura (Suruga), Setouchi (Inland Sea), Ōsaka, Awa, Kōchi (Tosa), Kagoshima, Chi-fu, Spain, France, Piedmont, Corsica, Naple, Tarent, Sicily, Ustica, Adria-Zara, Venedig, Morea, Tunis, Algeria, Balearen, Norway, Great Britain, Portugal, Mediterranean Sea, and from North Cape of 72° N. to Senegal of 15° N.

122. CYCLINA CHINENSIS CHEM.

BRAUNS, Geol. Env. Tōkio, p. 53.—LISCHE, Jap. Meeres-Conch., I., p. 126 and II., p. 111.—DESHAY, Traité Élém., I. 2, p. 526.—Proc. Zool. Soc. 1865, p. 196.—MORSE, Shell-Mound of Ōmori, p. 27.—Syst. Conch. Cab., XI. 1, p. 111.

Synonym:—*Venus sineusis* GMEL.; *Cyprina tenuitria* LAM.

Tabata (very abundant).

Living: Tōkyō, Yokohama, Ōmori (in Tōkyō Bay), Misaki (Sagami), Nagasaki, Tsu (Ise), Matsushima (Rikuzen), Shima, Higo, Kagoshima, Kōchi (Tosa), Formosa, Shanghai, Hongkong, East Coast of Cochín China, and China Sea.

123. **CLEMENTIA** AFF. **PAPYRACEA** GRAY.Pl. III. Figs. 6 *a* and *b*.

Syst. Conch. Cab., XI. 1, p. 251.—ADAM, Genera Recent Moll.—
KOEBELT, Illustr. Conch.—DESLAY, Cat. Bivalve Shells Brit. Mus., I.

Shinagawa (rare).

124. **TAPES DECUSSATA** DKR.VAR **PHILIPPINARUM** A. AD. and RVE.

Pl. III. Fig. 7.

BRAUNS, Geol. Env. Tōkio, p. 53.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 537.—LISCHKE, Jap. Meeres-Conch., I, p. 115.—
Syst. Conch. Cab., XI. 1, p. 180 and p. 230.

In spite of various opinions on the distinctions between the European and the Asiatic forms, the latter seems to me to be a mere variety of the former.

Ōji and Tabata (rare).

Pliocene—Crag (England).

Living: Tōkyō, Hakodate, Kitami (Hokkaidō), Enoshima and Misaki (Sagami), Tanoura (Rikuzen), Nagasaki, Ōshima (Izu), Setouchi (Inland Sea), Mogi (Hizen), Nagasaki, Formosa, West Coast of Sakhalin, Olga Bay, Rifunsiri I., Corea, Possjet Bay, Castries Bay, Cape Noto, Cape Tofuto, Singapore, China, East Indies, New Zealand, Java, Amboina, Alexander (Egypt), Britain, Lido (Mediterranean), Frankreich, Pyrenese Peninsula.

125. **TAPES RIGIDUS** GLD.

BRAUNS, Geol. Env. Tōkio, p. 37.—GOULD, Otia Conch., p. 85.

Ōji (frequent).

Living: Hakodate, Puget Sound, and Strait of De Fusca.

126. **TAPES EUGLYPTUS** PH.Pl. III. Figs. 8 *a*, *a'* and *b*.

LISCHE, Jap. Meeres-Conch., I., p. 119.—PHILIPPI, Abbild. and Beschr. &c.—RÖMER, Monogr. Venus.

Shinagawa (frequent).

Living: Nagasaki and Setouchi (Inland Sea).

CARDIIDÆ.127. **CARDIUM CALIFORNIENSE** DESHAYES.Pl. III. Figs. 9 *a* and *a'*.

BRAUNS, Geol. Env. Tōkio, p. 42.—MIDDENDORF, Sib. Reise, p. 248.—PILSBRY, Cat. Mar. Moll. Japan, p. 131.—LISCHE, Jap. Meeres-Conch., I., p. 144, and II., p. 125.—MIDDENDORF, Moll. Ross., II., p. 40.—Syst. Conch. Cab., X, 2, p. 45.

Shinagawa and Ōji (frequent).

Living: Tōkyō Bay, Hakodate, Etrofu, Nagasaki, Castries Bay, West Coast of Sakhalin, Behring Sea, Sitcha, Vancouver Is., Fuean Strait, Puget-Sound, Ochotsk Sea, Unalashka, and from Fusca Strait to Monterey (California).

128. **CARDIUM MUTICUM** RVE.

Pl. III. Fig. 10.

BRAUNS, Geol. Env. Tōkio, p. 42.—LISCHE, Jap. Meeres-Conch., I., p. 144.—DUNKER, Index Moll. Maris Jap., p. 211.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 517.

Synonym: —*C. japonicum* DKK.; *C. papyraceum* SCHRENCK.

Shinagawa and Ōji (frequent).

Living: Tōkyō, Hakodate, Tsu (Ise), Awa, Nagasaki, Kōchi (Tosa), East Coast of Luzon, and East Indies.

129. **CARDIUM BRAUNSI** TOK.

Pl. III. Figs. 11.

Shell very large, nearly trigonal, ventricose, equivalve, posteriorly closed; anterior and posterior sides nearly equal in curvature, ventral margin semicircular; umbones median and prominent; highly projecting radiating ribs, numbering twenty in a large specimen of 82^{mm} length; each rib rippled with very fine transverse ridges. Characterized by having a trigonal shape and a small number of ribs. Length 82^{mm}, height 88^{mm}, and breadth 50^{mm}.

Ōji (rare).

130. **CARDIUM TOKYOENSIS** TOK.Pl. III. Figs. 12 *a* and *a'*.

Shell ovate; anterior side rounded, posterior subtruncated, ventral, almost semilunar; umbones prominent; radial ribs forty two in number, alternating with tolerably deep narrow grooves; ribs smooth, crenulated only at the posterior part; cardinal teeth two, lateral tooth one on each side.

Length	Height	Breadth
38 ^{mm}	41 ^{mm}	26 ^{mm}
20 ^{mm}	21 ^{mm}	12 ^{mm}

This species differs from *C. burchardi* Dkr. in having smooth ribs, a rather rounded outline, and a wider dorsal part. It much resembles *C. unicolor* Sow. from the Philippines, but the latter has crenulated and more numerous ribs and a greater height (100 : 66).

One living specimen of this species in the collection of our College was found somewhere in Japan, but the locality is not given.

Shinagawa (rare).

LUCINIDÆ.

131. LUCINA BOREALIS LANNÉ.

BRAUNS, Geol. Env. Tōkio, p. 44.—WOOD, Crag Mollusca, II., p. 139.
 —WEINKAUFF, Conch. Mittelmeer., I., p. 162.—HÖRNES, Tertiär-
 becken Wien, II., p. 299.—Geol. Surv. California, Paleont. II.—
 JEFFREY, Moll. Lightning and Poreup. Exp.

Ōji (very abundant), Shinagawa (frequent).

This species is widely distributed, but now entirely extinct in Japan. It also occurs rarely in the Miocene (Italy, Austria, Poland, America) and in the Pliocene (Italy, Belgium, England, Norway, America etc.) In Diluvium it is found in Norway, Iceland, Sweden, Great Britain, Ireland, throughout Continental Europe to Mogador and Rhodus; Santa Barbara, San Pedro, Dead Man's Is., San Diego (America).

Living specimens are only rarely met with in the Mediterranean, viz. on the coast of Piedmont, Corsica, Sicily and Algeria. But in the Atlantic Ocean it is quite frequent, especially in Norway, Great Britain, Holland, France and North America. In the Pacific, it is found on the north-west coast of America although not at all frequent. From the above, it will be seen that this species mostly occurs in the arctic regions.

132. CRYPTODON CFR. FLEXUOSUS MONT.

TRYON, Struc. and Syst. Conch., III., p. 211.

Shinagawa (rare).

C. flexuosus MONT. was found living at Hakodate.

UNGULIDÆ.

133. *MYSIA PACIFICA* TOK.

BRAUNS, Geol. Env. Tōkio, p. 44.—WEINKAUFF, Conch. Mittel-Meer., I., p. 158.—WOOD, Crag Moll., II., p. 146.

BRAUNS described this species as *Diplodonta trigonula* BRONN, which according to a figure given by WOOD is much thickened in the interior of the shell and more triangular at the angle beneath the beak. Besides these two distinguishing characters I can find no other marked difference between the two species. The present species occurs very abundantly at Ōji, but has not been found living in Japan.

134. *MYSIA* AFF. *SEMIASPERA* PHIL.

Pl. III. Figs. 13 *a*, *b* and *b'*.

LISCHKE, Jap. Meeres-Conch., II., p. 134.

Shinagawa (rare).

Specimens similar to the fossil species have been found living at Nagasaki. *Mysia semiaspera* PHIL. is mentioned as living at Nagasaki, in the West Indies, at Mazatlan, Acapulco, Bachiade, San Blas in North Patagonia, Rio Janeiro, Puerto, Cabello and Tams, and in the northern part of N. America(?)

ERYCINIDÆ.

135. *LASEA STRIATA* TOK.

Pl. III. Figs. 14 *a* and *b*.

BRAUNS, Geol. Env. Tōkio, p. 43.—WOOD, Crag Moll., II., p. 125.

Shell small, orbicular, tumid, slightly equilateral, nearly circular; surface with visible concentric lines; umbones promi-

nent; hinge with two teeth on each valve and a trigonal pit for the reception of the ligament. Length 9.5^{mm} (or 7^{mm}); height 9.5^{mm} (or 6.5^{mm}); and breadth 8^{mm} (or 5^{mm}).

BRAUNS designated this species as *L. rubra* MONT., but the latter is distinguished by having no concentric striations, the surface being quite smooth.

Shinagawa (abundant), Ōji and Tabata (rare).

The species is known as living near Misaki (Sagami) and Shima.

136. **LASEA AFF. SUBORBICULARIS** MONT.

Pl. III. Figs. 15 *a* and *a'*.

BRAUNS, Geol. Env. Tōkiō, p. 43.—WOOD, Crag Moll., II, p. 119.—WEINKAUFF, Conch. Mittel-Meer, I., p. 174.—JEFFREY, Moll. Lightning and Porcup. Exp.—CHALL. Report, Vol. XIII., p. 201 and 203.

Ōji (rare).

L. suborbicularis MONT. was found in the Pliocene and Diluvium of Norway, Great Britain, Ireland and Italy; and known as living in the Mediterranean and Adriatic Seas, Indian Ocean, North-west Coast of America, France, Portugal, Piedmont, Naples, Sicily, Spain, Norway and Madeira.

ASTARTIDÆ.

137. **ASTARTE JAPONICA** TOK.

Pl. III. Figs. 16 *a*, *a'* and *b*.

Shell trigonal, compressed, thick, equivalved, concentrically ribbed; lunule impressed; ligament external; cardinal teeth existing in each valve; pallial line entire. Length 2.5^{mm} ; height 2.4^{mm} .

Shinagawa (rare).

The living species of this genus are chiefly found in arctic regions such as Behring Sea, Ochotsk Sea, Norway, Wellington Channel (North Canada), Kara Sea; but it also occurs in the United States, Great Britain and the Canaries. In Japanese waters not a single specimen belonging to the genus has ever been collected.

138. *CARDITA ROTUNDA* TOK.

Pl. III. Figs. 17 *a* and *a'*.

Shell oval, valves nearly equal in length and height, unequal, exceedingly thick; anterior side rounded, posterior shortened and somewhat narrowed; equally rounded on the ventral margin; surface with from eighteen to twenty radial ribs which are crenulated and separated by fine shallow grooves; umbones very prominent and directed anteriorly; margin crenulated; ligament external; hinge teeth two, posterior elongated; pallial line simple; lunule very small, lanceolate.

Length	15 ^{mm}	14 ^{mm}	13 ^{mm}	13 ^{mm}	9.5 ^{mm}
Height	15 ^{mm}	13 ^{mm}	13 ^{mm}	13 ^{mm}	9 ^{mm}
Breadth	13 ^{mm}	10 ^{mm}	10 ^{mm}	9 ^{mm}	7 ^{mm}

In Japan we find two species of *Cardita* which resemble this fossil one. They are *C. ferruginea* A. ADAMS and *C. vesitata* DESHAYES. But the fossil form is distinguished from *C. ferruginea* A. AD. by having a more rounded shape, more prominent and pointed umbones, and less breadth. *C. vesitata* DESHAYES differs from ours in having a very narrow shell (the breadth being only 7.5^{mm} and the length 17^{mm}) and less prominent umbones. *C. ventricosa* GLD. from Vancouver shows great

resemblance to the Japanese form, but the latter is to be distinguished by the thickness of the shell and the prominence of the umbone.

Shinagawa (frequent), Ōji (rare).

Order Asiphonida.

NUCULIDÆ.

139. NUCULA MIRABILIS HINDS.

BRAUNS, Geol. Env. Tōkio, p. 46.—WOOD, Crag Moll., II., p. 82.—
DUNKER, Index Moll. Maris Jap., p. 238.—WOODWARD, Man. Moll.
pl. 17, fig. 18.

Shinagawa (frequent).

Living: Tōkyō Bay, Kōbe, Nagasaki and Kagoshima.

This is the species taken by BRAUNS for *Nucula cobboldia* Sow. as I am now convinced by an examination of the specimens left by him in the Museum of our Science College.

140. NUCULA INSIGNIS GLD.

BRAUNS, Geol. Env. Tōkio, p. 46.—GOULD, Otia Conch., p. 175.—WOOD,
Crag. Moll., II., p. 82.—WOODWARD, Man. Moll., p. 117.

Shinagawa (abundant); Ōji (abundant).

Living: Hakodate, and East Coast of Japan at 37° N. Lat.

This species was also taken by BRAUNS for *N. cobboldia* Sow.

141. LEDA CONFUSA HANLEY.

BRAUNS, Geol. Env. Tōkio, p. 49.—LISCHE, Jap. Meeres-Conch., III.,
p. 109.

Ōji and Shinagawa (rare).

Living: Tōkyō Bay, Enoshima (Sagami), Hakodate and China Sea.

142. **YOLDIA LANCEOLATA** J. Sow.

Pl. III. Fig. 18.

BRAUNS, Geol. Env. Tōkio, p. 47.—WOOD, Crag. Moll., II., p. 88., and suppl., p. 115.—Arch. für Naturg., 51. 1., 1885, p. 14 and 256.—JEFFREY, Moll. Lightning and Porcup. Exp.

Synonym.—*Y. arctica* BROD.

Ōji (rare).

Pliocene—Red Crag (Brawdsey) and Mam. Crag (Chillesfold).

Diluvium—Norway, Sweden, Scotland and N.E. America.

Living in the circumpolar regions of North Atlantic and Pacific Ocean, and well known as a boreal species:—Nova Zembla, Jenissei, Iceland; Metschigmen Bay and Nytschigane Point in the Behring Sea; Puget Sound; Avatscha Bay, Seniavin Strait; Enoshima (Sagami) and Hakodate.

ARCIDÆ.

143. **ARCA INFLATA** RVE.

Pl. III. Figs. 19 *a* and *b*.

REEVE, Monogr. Arch. fig. 30.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 578.—Syst. Conch. Cab., VIII. 2.—BRAUNS, Geol. Env. Tōkio, p. 44.—LISCHE, Jap. Meeres-Conch., I., p. 146, and II., p. 144.—PHILSBY, Cat. Mar. Moll. Jap., p. 148.—MORSE, Shell-Mound of Ōmori, p. 26.—DUNKER, Index Moll. Jap., p. 235.

Synonym:—*A. broughtonii* SCHRENCK; *A. suberenata* LISCHE.

Tabata, Ōji and Shinagawa (abundant).

Living: Tōkyo, Tartary (Amur-Liman), East Coast of

Hokkaidō, Hakodate, Enoshima (Sagami), Awa, Miyajima (Aki), Loochoo Is., Philippines and Kingsmill Is.

144. *ARCA TENUIS* TOK.

Pl. IV. Figs. 1 *a* and *b*.

This species which greatly resembles *A. inflata* RVE., has hitherto been taken for the full-grown form of *A. subcrenata* LKE. But the full-grown specimens of *Arca tenuis* TOK. show both valves quite equal in shape and with no marginal crenulations caused by ribs. The distinctions from *A. inflata* RVE. are the following :

1. The shell is more pointed at the antero-dorsal edge.
2. The shell is thinner.
3. The umbones are wider apart and not abruptly pointed as in *A. inflata* RVE.; sometimes they are slightly depressed at the middle.
4. The shell surface slopes towards the posterior edge, gradually and not suddenly.
5. The breadth of the shell is generally less than in *A. inflata* RVE.
6. The ligamental area is decidedly narrower.

				No. of	
				ribs.	
<i>A. inflata</i> RVE. <div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> <div></div> </div>	(Tokyo)	87 ^{mm}	70 ^{mm}	54 ^{mm}	37
	(„)	71 ^{mm}	58 ^{mm}	49 ^{mm}	38
	(„)	39 ^{mm}	31 ^{mm}	28 ^{mm}	31
	(„)	78 ^{mm}	63 ^{mm}	51 ^{mm}	39
	(Enoshima)	90 ^{mm}	70 ^{mm}	58 ^{mm}	36
	(Loochoo Is.)	60 ^{mm}	48 ^{mm}	38 ^{mm}	39

		Length	Height	Breadth	No. of ribs.
<i>A. tenuis</i> Tok.	(Ôji)	91 ^{mm}	72 ^{mm}	60 ^{mm}	40
	(„)	95 ^{mm}	76 ^{mm}	66 ^{mm}	48
	(Shinagawa)	90 ^{mm}	69 ^{mm}	64 ^{mm}	45
	(„ „)	96 ^{mm}	78 ^{mm}	60 ^{mm}	44

Tabata, Shinagawa and Ôji (frequent).

145. *ARCA GRANOSA* LINNÉ.

Pl. III. Fig. 20.

BRAUNS, Geol. Env. Tôkio, p. 66.—MORSE, Shell-Mound of Ômori, p. 26.—LISCHE, Jap. Meeres-Conch., I., p. 145.—PILSBRY, Cat. Mar. Moll. Japan, p. 148.—SOWERBY, Genera rec. and foss. Shells.—REEVE, Monogr. Arca, fig. 15.—Syst. Conch. Cab., VIII. 2, p. 38.—PETERMANN'S Geogr. Mittheil., X., XI., XII.

Tabata (frequent).

Diluvium—Tempé (South Celebes).

Found in Neolithic Shell Mounds, but now extinct in Tôkyô Bay.

Living: Enoshima (Sagami), Tottori, Imô (Bicchû), Okayama, Nagasaki, Hyakwanzaki (Higo), Cochin China, Chi-fu, Philippines, Singapore, Cape St. Jacques, Ceram, Celebes, Tranquebar, Nicobar, Java, Mergui and E. Indies.

146. *ARCA KAGOSHIMENSIS* TOK.

Pl. III. Figs. 21 *a* and *b*.

Shell small, solid, oblong, tumid; anterior side rounded; posterior subtruncated; surface sculptured with from thirty-one to thirty-four finely granulated radial ribs, with interstices broader than the ribs; umbones slightly directed anteriorly; teeth numerous.

Length	Height	Breadth	No. of ribs.
26 ^{mm}	20 ^{mm}	18 ^{mm}	31
15 ^{mm}	12.5 ^{mm}	12 ^{mm}	34

Arca troscheli Dkr. strongly resembles this species, but the anterior and posterior edges of the dorsal margin are more prolonged, and the number of ribs is only twenty four in a specimen of 22^{mm} length.

Ōji (rare).

The living specimens of this species were collected at Kagoshima.

147. *ARCA* α sp.

Pl. III. Figs. 22 *a* and *b*.

The present form seems to be a young of some species of *Arca*. It is only rarely found at Ōji and is characterized by the beaked shape, the form of the postero-dorsal angle, the very small ligamental area and the oblique teeth.

Living specimens were collected near Misaki (Sagami). Length 9^{mm}; height 8^{mm}; breadth 7^{mm}.

148. *ARCA* β sp.

This species frequently found at Ōji is nearly rectangular, the breadth very small and the posterior portion of the shell much elongated. Length 15^{mm}; height 9^{mm}; breadth 7.5^{mm}. Like the preceding it seems to be a young specimen of some species of *Arca*.

149. *ARCA* γ sp.

This species abundantly found at Ōji, but rare at Shinagawa, has a nearly rectangular shape at the dorso-anterior edge;

the posterior half of the dorsal margin is also much produced and straight, giving a distinctly truncated shape at the posterior side. The umbones are sunken at the middle. It may however be a young form of some other species of *Arca*.

150. **ARCA RECTANGULARIS** TOK.

Pl. III. Figs. 23 *a*, *b* and *c*.

Shell subquadrate, gaping anteriorly and posteriorly; anterior side short, distinctly truncate, the posterior surface of the shell distinctly marked off from the anterior; dorsal side almost straight, angulate at the antero-dorsal margin; ventral margin curved in the middle; surface with fine granulated radial ribs; hinge linear, straight, formed of a large number of small pectinated teeth; ligament external, attached on a very broad lozenge-shaped area between the beaks; beaks high, rather wide apart. Length 15^{mm}; height 7^{mm}; breadth 11.5^{mm}.

Our species differs slightly from *A. navicularis* BRUG. found in the Indian Ocean and the Philippines by its thicker shell and more numerous ribs in the anterior part. *A. nov* LINX. differs from ours, firstly, in its size and in the shape of the posterior side, secondly in having more than thirty ribs without intermediate riblets, and thirdly in the form of the posterior portion of the internal surface. *A. maculata* RYE. much resembles the Japanese species, but its antero-dorsal margin is almost rectangularly truncated.

Shinagawa (very rare).

The living specimens were collected at Hakodate.

151. **PECTUNCULUS ALBO-LINEATUS** LISCHKE.

BRAUNS, Geol. Env. Tōkio, p. 45.—WOOD, Crag Moll., II., p. 66, and suppl. p. 43.—LISCHE, Jap. Meeres-Conch., III., p. 108.

BRAUNS took this species as identical with *P. glycimeris* L. from the Mediterranean Sea and Great Britain, but these two species seem to me to have many points of difference. Firstly, *P. glycimeris* L. is quite orbicular and equilateral, having the same dimensions in length and height, while our species is oval, and inequilateral, the length being greater than the height; secondly, *P. glycimeris* L. has a broader ligamental area; thirdly, the breadth is decidedly less in *P. albo-lineatus* LKE. than in *P. glycimeris* L.

Ōji (very abundant), Shinagawa (frequent).

Living: Tōkyō, Possjet Bay, Hakodate, Kitami, Bekkai (Hokkaidō), Aomori, Kii, Izugahara (Tsushima), Tosa and Fusan (Corea).

152. **LIMOPSIS WOODWARDI** A. ADAMS.

BRAUNS, Geol. Env. Tōkio, p. 57.—DUNKER, Index Moll. Maris Jap., p. 237.—Rep. Chall. Exp., Vol. XIII., p. 256.—WOOD, Crag Moll., II, p. 70.

BRAUNS determined the specimens of this species abundantly found at Ōji as *L. aurita* BR. hitherto found in the Crag and the Miocene of North Germany and the Sub-appennine formation, and said that this still living species only known from the N. W. Coast of Britain had been found neither in the Pacific Ocean, nor in the East Indian Seas. But by a careful study I have found many differences between them: firstly, the umbones in *L. aurita* BR. are not central but turned forwards, thus giving an oblique inequilateral outline to the shell; secondly, the breadth is greater in *L. aurita* BR.; thirdly, *L. woodwardi* A. AD. is distinctly angular at both edges of the dorsal side, while in *L. aurita* BR. they are rounded. Beside these signi-

ficant differences, a still more important distinction is that *L. aurita* Br. has a nearly smooth surface.

Shinagawa (very abundant).

Living in Japan.

MYTILIDÆ.

153. *MODIOLA MODIOLUS* LINNÉ.

Pl. III. Fig. 24.

REEVE, Monogr. Modiola, fig. 2.—Syst. Conch. Cab., VIII. 3, p. 93.—WOOD, Crag Moll., II., p. 57.—PILSBRY, Cat. Mar. Moll. Japan, p. 139.—MIDDENDORF, Mal. Ross., II., p. 21.—Verh. Russ-Kais. Miner. Gesell. St. Petersburg, II series, XXXVIII Band, I. 1900.

Synonym:—*M. papuana* LAM., *M. vulgaris* FLEMING; *M. barbata* L.; *Mytilus umbilicatus* PENNANT; *M. curtus* PENNANT; *M. curvirostratus* DA COSTA.

Tabata (very rare).

Pliocene—Red Crag (Sutton) and Mamm. Crag (Postwick, Brindlington).

Post-pliocene—White Sea and the western part of Murman Sea.

Living: Tōkyō, Hakodate, Setouchi (Inland Sea); Sitcha Is.; St. Paul Is. and Kadjak in Behring Sea; Kildrin Is. in Russ. Lapland, Russia; whole North Atlantic Coast of Europe and America—North Seas, Scarborough (England), Neeah Bay, Kinnibei Floro (Norway), Eastport (Maine U.S.), New England; and Mediterranean Sea.

154. *MODIOLA* AFF. *JAPONICA* DKK.

Pl. III. Figs. 25 *a* and *b*.

REEVE, Monogr. Modiola,—Syst. Conch. Cab., VIII. 3, p. 139.

Shinagawa (rare).

Living specimens were collected near Tōkyō and Hakodate.

PINNIDÆ.155. **PINNA** SP.

Only found as fragments at Ōji.

LIMIDÆ.156. **LIMA** AFF. **JAPONICA** A. ADAMS.

Pl. III. Figs. 26 *a* and *b*.

HUTTON, New Zealand Moll., p. 172.

Shinagawa (rare).

Living specimens were collected near Hakodate, and also 3 miles off Misaki (Sagami). *Lima japonica* A. ADAMS was found near Stewart Is. and also in Japan.

157. **LIMA** **HAKODATENSIS** TOK.

Pl. III. Figs. 27 *a* and *b*.

Shell distinctly inequilateral, and thin; posterior side produced, anterior slightly angular; dorsal margin straight; surface with numerous rather indistinct scaly radial ribs which are crossed by a few indistinct concentric lines. Length 26^{mm}; height 32.5^{mm}; breadth 20^{mm}.

Shinagawa (frequent).

Living specimens were collected at Hakodate.

PECTINIDÆ.158. **PECTEN** **LAQUEATUS** SOW.

BRAUNS, Geol. Eny. Tōkio, p. 48.—LISCHE, Jap. Meeres-Conch., I, p. 167, and II, p. 157.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres.—PILSBRY, Cat. Mar. Moll. Jap., p. 143.—Report Chall. Exp., Vol. XIII., p. 307.

Ōji (frequent), Shinagawa (rare).

Living specimens are very common in Japan, but their occurrence is limited to the western coast of the North Pacific Ocean and to the north-west coast of N. America, probably not extending far from California. In Japan they occur in the following places: Tōkyō Bay, Misaki and Koajiro (Sagami), Ajiro (Izu), Chōshi (Shimōsa), Hakodate, Sapporo, Enoura (Suruga), Takashima (Kii), Futamiga-ura (Ise), Sakai (Settsu), Ōsaka, Kōbe, Tsuruga (Echizen), Tomo (Bingo), Awaji, Miyajima (Aki), Gōnoura (Iki), Nagahama (Iyo), Asamiwan (Tsu-shima), Nagasaki, Kanze (Satsuma), Kagoshima, and Loochoo Is.

159. **PECTEN LETUS** GLD.

Pl. IV. Fig. 2.

LISCHKE, Jap. Meeres-Conch., I., p. 169, and II., p. 157.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 603.—BRAUNS, Geol. Env. Tōkio, p. 57.—PHILSBRY, Cat. Mar. Moll. Jap., p. 143.

Shinagawa and Ōji (frequent).

Living: Tōkyō Bay, Jōgashima (Sagami), Chōshi (Shimōsa), Hakodate, Rikuzen and Nagasaki.

160. **PECTEN TOKYOENSIS** TOK.

Pl. V. Figs. 1-10.

BRAUNS, Geol. Env. Tōkio, p. 48.—SOWERBY, Thes. Conch., I., p. 65.—Syst. Conch. Cab., VIII. 2, p. 256.

Shell very large reaching 150^{mm} in length, equilateral, inequivalved, thin, nearly round in outline. Right valve strongly swollen; surface with undulating ribs and furrows: ribs very

broad without any distinct limit toward the interstices; they number three or more near the central part of the shell, where each rib is broadest at the ventral margin of the shell, being about 3^{mm} in breadth, and again divided into three or more riblets; near the anterior and posterior portion of the shell broad ribs are separated by a very narrow interspace, and a few coarse lines of growth are visible; in the younger specimens, the furrows and ribs are more sharply bordered, the interspace being wider; ears nearly symmetrical, radially ribbed, the anterior one only slightly notched. Left valve almost flat, only very slightly swollen; ribs few, eight in number, sharp and keel-like beneath the umbones, but becoming less sharp near the ventral margin; interspaces broad and smooth, with very fine concentric scaly lines; ears radiately striated, the anterior one higher and furnished with broad grooves.

	Length	Height	Breadth
Right valve	140 ^{mm}	136 ^{mm}	30 ^{mm}
„	114 ^{mm}	114 ^{mm}	22 ^{mm}
„	55 ^{mm}	53 ^{mm}	10 ^{mm}
„	37 ^{mm}	35 ^{mm}	8 ^{mm}

This species which is abundant at Ōji, and in some Tertiary districts in Japan, was identified by BRAUNS with *Pecten plica* L., but according to my own observations, there exist many points of difference between the two. *P. plica* L. is a small shell with a very small auricle, nearly equal blunt radial striations, and only three central ribs and two much smaller ones in each valve. These characters alone are sufficient to prove that they do not belong to the same species.

161. **PECTEN** AFF. **IRRADIANS** LAM.

Pl. IV. Fig. 3.

SOWERBY, Thes. Conch., I, p. 20.—Syst. Conch. Cab., VII. 2, p. 77,
and p. 208.

Shinagawa (very rare).

162. **PECTEN PULCHELLIMUS** TOK.

Pl. IV. Fig. 4.

Shell small, round, radially ribbed; ribs sixteen in number, without any distinct limit toward the interstices; surface without concentric ribs, but with a few undulating lines of growth; ears unequal, the anterior one more prominent, radially striated, with a distinct notch below, the posterior one serrated. Length 9^{mm}; height 10^{mm}.

Ōji (rare).

ANOMIIDÆ.163. **ANOMIA** AFF. **PATELLIFORMIS** LINNÉ.

BRAUNS, Geol. Env. Tōkio, p. 49.—WOOD, Crag Moll., II., p. 11.—
JEFFREY, Moll. 'Lightening' and Porc. Exp.

Tabata and Ōji (frequent), Shinagawa (rare).

Living specimens were collected near Misaki (Sagami).

A. patelliformis L. is found as a fossil in the Cor. Crag (Sudbourn and Sutton), Red Crag (Sutton, Bawdsey, and Walton Naze), Pliocene and Diluvium of Scandinavia, Great Britain, Ireland, Belgium, Vienna Basin and Italy. It is also known to live in Britain, Scandinavia, Faroe Is., Mediterranean and Adriatic Sea, N. W. America, and probably in Japan.

OSTREIDÆ.

164. **OSTREA GIGAS** THUNB.Pl. IV. Figs. 5 *a* and *b*.

BRAUNS, Geol. Env. Tōkio, p. 48.—LISCHKE, Jap. Meeres-Conch., I, p. 174, and II., p. 160, and III., p. 114.—SCHRENCK, Moll. Amurl. and Nord-Jap. Meeres, p. 475.—REEVE, Monogr. Ostrea Sp., 21.

Synonym:—*O. talienwanensis* CROSS; *O. laparousii* SCHRENCK.

Ōji and Shinagawa (frequent).

Living: Tōkyō Bay, Chōshi (Shimōsa), Wadanohara (Rikuzen), Nagasaki, Tehifu, and Talienwan.

165. **OSTREA DENSELAMELLOSA** LKE.Pl. IV. Figs. 6 *a* and *b*.

BRAUNS, Geol. Env. Tōkio, p. 58.—MORSE, Shell-Mound of Ōmori.—LISCHKE, Jap. Meeres-Conch., I, p. 177.

Ōji and Shinagawa (frequent).

Living: Tōkyō, Sumoto (Awaji), South Shikoku, Bungo, and Loochoo Is.

166. **OSTREA IRREGULARIS** TOK.Pl. IV. Figs. 7 *a* and *b*.

Shell small, very irregular, convex; valves nearly equal in length and breadth; surface plaited or spinous, somewhat foliated, concentric striations usually invisible.

Tabata (very abundant).

Living specimens were collected near Misaki (Sagami).

Vermes.**Brachiopoda.****TEREBRATULIDÆ.****WALDHEIMIA GRAYI** DAVIDSON.

Pl. IV. Figs. 8 *a* and *b*.

BRAUNS, Geol. Env. Tōkio, p. 58.—DAVIDSON, Jap. Brachiopod, p. 300.

—DAVIDSON, Monogr. Rec. Brachiopoda, p. 54.

Shinagawa (very rare).

Living: Hakodate, Hitachi, Matsushima (Rikuzen), and Strait of Corea.

WALDHEIMIA ELONGATA TOK.

Pl. IV. Figs. 9 *a* and *b*.

The shell is more elongated than in the preceding species, with apex more prominent and projecting; the shape of the hinge-portion of the shell is also quite different; ribs less distinct; foramen complete.

Shinagawa (very rare).

LINGULIDÆ.**LINGULA HIANI** SWAINS.

Pl. IV. Fig. 10.

DAVIDSON, Monogr. Rec. Brachiopoda, p. 216.

Ōji (very rare).

Living: Enoshima and Moroiso (Sagami), China Sea, Australia.

Echinodermata.**Echinoidea.****TEMNOPLEURUS TOREUMATICUS KLEIN.**

A. AGASSIZ, Rev. Echini, p. 463.—A. AGASSIZ, Report Chall. Exp., p. 108.—A. AGASSIZ. List Echinoderm &c. (Bull. Mus. Comp. Zool. Harvard Coll., Vol. I., 1863).—BELL, Observ. Charac. Ech. &c. (Proc. Zool. Soc. London, 1880, p. 423).—MARTIN, Tertiärschichten auf Java; Anhang p. 1).—DÖDERLEIN, Seeigel Jap. and Liukiu Ins. (Arch. f. Natur., I., 5, 1885, p. 73).—IVES, Echinod. and Arthr. Japan. (Proc. Acad. Nat. Sc. Ph., 1891).

Synonym:—*T. hardwicki* AGASS.; *T. bothyoides* AGASS.; *T. reevesii* A. AGASS.; *Echinus sculptus* LAMK.

Miocene—Java.

Shinagawa and Ōji (frequent).

Living: Tōkyō Bay, Misaki (Sagami), Hakodate, Sendai (Rikuzen), Wakanoura (Kii), Kōbe, Maizuru and Miyatsu (Tango), Tomo (Bingo), Miyatsu (Tango), Nagasaki, Tsuruga (Echizen), Kagoshima, Kamtschatka, Hongkong, North China, Philippines, Arafura Sea, Unalaska, Gulf of Persia, Karrax I., Siam, Ceylon, and East Indies.

LAGANUM DECAGONALIS LESS.

A. AGASSIZ, Rev. Ech., p. 520.—A. AGASSIZ, Report dredg. Gulf Mexico "Blake."—BELL, Echinod. coll. 'Perguin' and 'Egeria' &c. (Proc. Zool. Soc. London, 1894).—DÖDERLEIN, Seeigel Japan and Liukiu Ins. (Arch. f. Naturg., I., 51 Jahr., 1885, p. 73).—MARTIN, Tertiärschichten auf Java, Anhang p. 3.—DUNCAN, Rev. Genera and Great Group Ech., p. 156.

Synonym:—*L. lesueurii* VAL.; *L. elongatum* AGASS.; *L. australe* GRAY; *Polyaster elegans* MICH.

Miocene—Java.

Shinagawa and Ōji (rare).

Living : Tōkyō Bay, Misaki (Sagami), Wakanoura (Kii) Kagoshima, Hongkong, Philippines, Gasper Strait, Frumanth Bay, Australia, Bay of Bengal, New Caledonia, Torres Strait Amboyna, Tongatabu, Paputi, and Tahiti.

ECHINARACHNIUS MIRABILIS BARN.

A. AGASSIZ, Rev. Ech., p. 526.—DÖDERLEIN, Seeigel Jap. and Liukiu Ins.

Synonym :—*Chaetodiscus scutella* LÜTK.; *Scutella japonica* MART.

Shinagawa (rare).

Living : Tōkyō Bay, Misaki (Sagami), Tomo (Bingo), Hakodate, and Otaru (Hokkaidō).

FIBULARIA ACUTA YOSIL.

YOSHIWARA, Prelim. Notice new Jap. Ech. (Ann. Zool. Jap., Vol. II.,

Pars II., 1898, p. 57).—TOKUNAGA, Fossil Ech. Jap. (Journ. Coll.

Sc. Imp. Univ. Tokyo Japan, Vol. XVII., Art. 12, p. 7).

As to a fossil the species of *Fibularia* were only found in the Upper Cretaceous and the Eocene.

Ōji (rare).

Living at Misaki (Sagami) and Shigajima (Chikuzen).

Vertebrata.

Vertebrate remains are very seldom met with. If we except indeterminable fragments of bones of fishes we have the following three important species.

MYLIOBATIS Sp.

Pl. VI. Fig. 1.

A part of a tooth of ray-fish was found at Tabata by Prof. YOKOYAMA. It is one of those flat, rectangular plates, which, when the tooth is perfect, are placed close together, united by suture, and laterally adorned with many small rhombic plates, so as to form a kind of mosaic pavement on both the upper and lower jaws. Our plate measures 30^{mm} in length, 5.5^{mm} in thickness. The inner surface is furnished with twenty-eight ridges and furrows.

The shape of the plate resembles that of the Japanese *M. cornuta* GTHR. found in the sea near Rikuzen and Hizen. But the latter, in which the head is 6^{cm}, the trunk 24.5^{cm} and the tail 35^{mm} long, and which is probably one of the largest forms, a dental plate of only 14^{mm} in length, 3.5^{mm} in width and 2^{mm} in thickness.

ELEPHAS ANTIQUS FALC.

Pl. VI. Figs. 2-6.

NAUMANN, Jap. Elephant der Vorzeit, 1881, p. 25.—BRAUNS, Geol. Env. Tōkio, 1881, p. 24.—BRAUNS, Ueber Jap. Dil. Säugethiere (Zeitschr. deuts. geolog. Gesells., I., 1883).—ROGER, Vez. bisher bekannten fossilen Säugethiere (Naturw. Vereins Schwaben und Neuburg. Augsburg, 1896).—FALCONER, Palaeontological Memoirs, II., p. 147.—FALCONER and CAUTLEY, Fauna antiqua Sivalensis.

Synonym:—*E. namadicus* FALC. and CAUT.

This interesting fossil mammal was dug out, in the year 1898, from the lower part of a bluish clay at Tabata. The specimens consist of two molar teeth (Pl. VI. Figs. 2-5) and a splendid tusk (Pl. VI. Fig. 6.) which are now in the Imperial

University of Tōkyō. Subsequently some fragments of skeletons were also collected by Prof. YOKOYAMA and myself.

The molar teeth are both broken at the anterior end. The crown of the larger specimen (Pl. VI. Figs. 2 and 3) exhibits the discs of seven worn ridges, the anterior most being half broken. The anterior five ridges are worn down into transverse discs, but the penultimate one is more slightly worn into two irregular shaped bands, while the most posterior one shows only the summits of five small digitations. The anterior four discs are worn off short, but the others are less so, the degree of wearing gradually diminishing as we go backwards. Each disc is rounded at its lateral terminations, and has a crescentic shape, the anterior enamel boundary being somewhat concave and the posterior convex. The horns of the crescent are bent abruptly forwards. There is a rhomboidal expansion in the middle of the third and fourth discs, which is 1.15^{cm} , measured between the outer surfaces of the enamel. The enamel plates are thick and their outer edges present an appearance of considerable crimpling, caused by the deep vertical grooving of the outer surface. The grinding surface is concave from back to front. The extreme length of the crown surface is 9.2^{cm} , and the width at the first ridge 4^{cm} , at the fourth 5.3^{cm} , and at the last ridge 3.6^{cm} . The greatest height of the tooth is 10.2^{cm} . It is evident that, the tooth, when entire, was composed of about nine ridges, and that it was about 12^{cm} long. The inner side of the tooth is convex as seen in the other specimens of *Elephas*, and the outer edge concave in the upper view of the crown.

The other specimen (Pl. VI. Figs. 3 and 4.) has a large part of its anterior half broken off. We find in it only three

discs and two posterior less digitated ridges. The two anterior discs are very much abraded, the enamel edge of the succeeding one strongly projecting above them. The penultimate ridge is partly worn and forms separate, transverse or oval bands. The last ridge is almost wholly broken off. The width of the crown at the first ridge is 5^{cm}, while its greatest height is 10^{cm}.

From the general form of the teeth, the shape and number of the ridges, the mode of crimpling of the enamel plates, and other characters, our specimens seem to belong to the third premolar of *E. antiquus* FALC. or *E. namadicus* FALC. and CAUT. Compared with the specimen found at Edobashi in Tōkyō our specimens are much smaller both in the height and length of the crown, but among the specimens described as third premolars of *E. antiquus* FALC. in "*Palaeontological Memoirs*," there is one having a crown 12.4^{cm} or even 10.7^{cm} in length. Therefore I am quite justified in referring our two specimens to the third premolar, the larger being probably one belonging to the right side of the upper jaw, and the smaller to the left side of the same.

Furthermore the anterior portion of a tusk (Pl. VI. Fig. 6.) of the same species was dug out from the same locality. It is somewhat curved, with the cross section at the posterior extremity slightly elliptical where it has a diameter of about 9^{cm}.

Hitherto there has been great confusion in the distinction of the two species, *E. antiquus* FALC. and *E. namadicus* FALC. and CAUT. This has been due to the fact that it is very difficult to distinguish them merely by the form and structure of the teeth. In our country, elephants belonging to the above two species have been found at several places. NAUMANN, in his "*Japanische Elephanten der Vorzeit*," identified them with

E. namadicus FALC. and CAUT. found in the Pleistocene of India, while BRAUNS determined them to belong to *E. antiquus* FALC. found in Europe and Northern Asia. According to the latter author all the Japanese elephants are to be taken as Diluvial forms. According to several works relating to these two species it seems to me that there do not exist sufficient characters to separate the Indian form from the European and North Asiatic one. Therefore it will be preferable to follow OTTO ROGER, and to consider them as belonging to one and the same species.

INDETERMINABLE UNGULATE BONE.

Pl. VI. Fig. 7.

Only the articulating portion of a limb of an indeterminate *Ungulate* was found together with *E. antiquus* FALC. at Tabata.

CONCLUSION.

BRAUNS collected the fossils of *Mollusca* and *Brachiopoda* at Ōji, Shinagawa and Surugadai, and described :
from Ōji,

26 *Gastropoda*, 2 *Scaphopoda* and 33 *Pelecypoda* ;

from Shinagawa,

13 *Gastropoda*, 1 *Scaphopoda*, 21 *Pelecypoda* and 1
Brachiopoda ;

from Surugadai,

7 *Gastropoda*, 1 *Scaphopoda* and 17 *Pelecypoda* ;

making in all 75 different species from the three localities: thus

33 *Gastropoda*, 2 *Scaphopoda*, 39 *Pelecypoda* and 1 *Brachiopoda*.

I myself have collected at Ōji

45 *Gastropoda*, 2 *Scaphopoda*, 48 *Pelecypoda* and 1 *Brachiopoda* ;

at Shinagawa

47 *Gastropoda*, 3 *Scaphopoda*, 52 *Pelecypoda* and 2 *Brachiopoda* ;

at Tabata

27 *Gastropoda* and 15 *Pelecypoda* ;

in total 168 different species, viz.,

87 *Gastropoda*, 3 *Scaphopoda*, 75 *Pelecypoda* and 3 *Brachiopoda*.

The following species mentioned by BRAUNS from Ōji, Shinagawa and Surugadai are not found in my collections. This is mainly due to the fact that my determinations are in many cases different from his.

Columbella scripta LINNÉ; *Mangelia striolata* PHIL.; *Trichotropis coronata* GLD.; *Bulla cylindracea* PENN.; *Dentalium entale* LINNÉ; *Solen grandis* DEK.; *Lusca rubra* MONT.; *Pectunculus glycymeris* LINNÉ; *Nucula cobboldie* SOW.; *Limopsis aurita* BROD.; *Pecten plica* LINNÉ; *Scalaria clathratula* MONT.; *Scalaria cancellata* BROD.

Looking at all the species described, it is quite certain that our fossil bearing layers are deposits of a shallow sea.

In settling the question whether our fossil *Mollusca* belong to a fauna, warmer or colder than the living, 117 species out of 165 are to be availed of, for the remainder are either extinct or are such as are very rarely found in a living state.* Among the 117 species I find the following 26 tropical ones:

Rapana bezoar L.; *Triton saulie* L.; *Hemifusus ternatanus* GMEL.; *Nassa livescens* PHIL.; *Cancellaria spengleriana* DESH.; *Terebra alveolata* HINDS.; *Pleurotoma oxytropis* SOW.; *Pleurotoma gracilentia* RVE.; *Dolium luteostomum* KÜNSTER; *Sigaretus papilla* GMEL.; *Scalaria immaculata* SOW.; *Scalaria lamellosa* LAM.; *Scalaria acuminata* SOW.; *Turbonilla fusca* A. AD.; *Pyramidella spirata* A. AD.; *Cerithium kochii* PHIL.; *Potamides fluviatilis* PORT. and MICH.; *Potamides incisus* HINDS and JACQ.; *Turbo granulatus* GMEL.; *Trochus amussitatus* GLD.; *Trochus argyrostomus* GMEL.; *Dentalium octogonum* LAMK.; *Venus foliacea* PHIL.; *Cytherea meretrix* L.; *Cardium muticum* RVE.; *Arca granosa* L.

And to the arctic species belong the following seventeen:

Neptunea despecta LINNÉ; *Buccinum undatum* LINNÉ; *Natica clausa* DESH.; *Trichotropis unicarinata* BROD.; *Solen krausensternii* SCHRENCK; *Panopæa generosa* GLD.; *Mactra sachalinensis* SCHRENCK; *Mactra sulcataria* DESH.; *Tressus nuttali* CONRAD; *Tellina tenera* SAY; *Macoma nasuta* CONRAD; *Venus stimpsoni* GLD.; *Cytherea chinensis* CHEM.; *Tapes rigidus* GLD.; *Cardium californiense* DESH.; *Astarte japonica* TOK.; *Yoldia lanceolata* SOW.

* It must be acknowledged that our three localities belong to the same facies. The reasons are explained later on.

The following seven species are found in latitudes both north and south of Japan, and for the most part are world-wide in distribution :

Martesia striata LINNÉ; *Saxicava arctica* DESH.; *Saxidomus nuttali* CONRAD; *Dosinia exoleta* L.; *Tapes decussata* DKR.; *Lucina borealis* L.; *Modiola modiolus* LINNÉ.

The remaining ones are those found only in Japan (or in the same latitude in Eastern Asia).

(I) Species chiefly found south of Tōkyō :

Fusus nodoso-plicatus DKR.; *Fusus simplex* E. A. SMITH; *Nassa japonica* AD.; *Erato callosa* AD. and RYE.; *Columbella martensi* LKE.; *Columbella pumila* DKR.; *Cancellaria nodulifera* SOW.; *Terebra subtextilis* E. A. SMITH; *Terebra* cfr. *serotina* AD. and RYE.; *Pleurotoma subauriformis* E. A. SMITH; *Pleurotoma varicostata* SMITH; *Natica ampla* RYE.; *Odostomia fasciata* DKR.; *Odostomia planata* GLD.; *Pyramidella cinctella* A. AD.; *Acmæa conulus* DKR.; *Tornatina exilis* DKR.; *Dentalium* cfr. *weinkauffi* DKR.; *Næra gouldiana* HINDS; *Myodora fluctuosa* GLD.; *Maetra veneriformis* DESH.; *Maetra crossei* DKR.; *Tellina nitidula* DKR.; *Tellina yedoensis* LKE.; *Tellina rutila* DKR.; *Tellina nipponica* TOK.; *Lutraria ovalis* TOK.; *Cyclina chinensis* CHEM.; *Tapes euglyptus* PH.; *Nucula mirabilis* HINDS; *Arca kago-shimensis* TOK.; *Ostrea denselamellosa* LKE.

(II) Species chiefly found north of Tōkyō :

Trophon exiguus TOK.; *Volutharpa perryi* JAY; *Nucula insignis* GLD.; *Terebra bipartita* GLD.; *Cryptodon flexuosus* MONT.; *Arca rectangularis* TOK.; *Modiola japonica* DKR.; *Lima hakodatensis* TOK.

(III) Species found both north and south of Tōkyō.

Murex falcatus SOW.; *Fusus perplexus* A. AD.; *Siphonalia cassidareiformis* RYE.; *Eburna japonica* SOW.; *Clivella consobrina* LKE.; *Pleurotoma principalis* PILSBRY; *Natica papyracea* BUSH.; *Potamides zonale* BRUG.; *Rotella costata* LESSON; *Trochus imperialis* A. AD.; *Trochus*

japonicus A. AD.; *Ringicula arcata* GLD.; *Solen gouldi* CONRAD;
Macha divaricata LKE.; *Leda confusa* HANLEY; *Arca tenuis* TOK.;
Pectunculus albo-lincatus LKE.; *Limopsis woodwardi* A. AD.; *Pecten*
laqueatus SOW.; *Pecten letus* GLD.; *Ostrea gigas* THUNB.

(IV) Species found only near Tōkyō or in places of nearly equal latitude in Eastern Asia:

Pleurotoma reciproca GLD.; *Pyramidella eximia* LKE.; *Fissurella lischkei*
 PHILSBRY; *Lasaea striata* TOK.; *Gari radiata* DKR.; *Ostrea irregu-*
laris TOK.

The following list shows the distribution of the species living in the sea near Tōkyō.

(A) Tropical species (114 sp.)

Arca kraussii PHIL.—East coast of Japan, Tōkyō to Awaji, Nagasaki and Africa.

* *Arca granosa* L.—Enoshima, Nagasaki, Hyakwanzaki, Tehifu, Singapore, Philippines, Cape St. Jacques, Cochin China, Ceram, Celebes, Tranquebar, Nicobar, Java, Mergui, E. Indies.

Cancellaria asperella LAM.—Yokohama, Inland Sea, Kinshū, Tōkyō, Tōmo, China, Philippines.

* *Cancellaria spengleriana* DESH.—Enoshima, Misaki, Shimoda, Chōshi, Kōbe, Nagasaki, Wakanoura, Setouchi, China, Philippines, Australia.

Cantharus undosa LINNÉ.—Yokohama, Molucca.

Collumbella scripta LAM.—Ōshima, Tōkyō Bay, Nagasaki, Ukushima, Gotō Is., Philippines, Indian Ocean, Australia, Polynesia.

Collumbella misera SOW.—Nagasaki, Gotō Is., Kamakura, Tōkyō Bay, Ise, N. Shore of Tongo. New Zealand, Paumotu, Sandwich Is.

Cassis strigata GMEL.—Tōkyō Bay, Setouchi, Sagami coast, China, Molucca, Philippines.

Cypræa arabica LINNÉ.—Tōkyō, Tago, Samoa, New Caledonia, Australia, Indian Ocean.

Cypræa tigris LINNÉ.—Tōkyō, Satsuma, Pacific and Indian Ocean.

Cypræa macula ADAMS.—Australia, Awa (or Bōshu), Tsuruga, Ōshima, Kii, Enoshima (Ōshima), Formosa, N. Coast of Tongo.

Cypræa felina GMEL.—Nagasaki, Kino-Ōshima, Misaki, Kii, Nijima, Formosa, Indian Ocean.

- Cypræa lutea* GROX.—Awa (or Bōshu), New Caledonia, Australia.
- Cypræa poraria* L.—Awa (or Bōshu), Formosa, Ogasawarajima, Hachijō, Fiji, Australia, New Caledonia.
- Cypræa onoyx* LINNÉ.—Tateyama, Tanabe, Tsu-saki, Ceylon, Philippines.
- Cypræa lynx* LINNÉ.—Tōkyō, Indian Ocean, Australia, New Caledonia, Red Sea.
- Cypræa clandestina* LINNÉ.—Tateyama, Tsushima, Kino-Ōshima, Ceylon, Australia.
- Cypræa miliaris* GMEL.—Tōkyō Bay, N. S. Wales.
- Cypræa erosa* LINNÉ.—Yokohama, Tanabe, Takanoshima, Pacific and Indian Ocean.
- Cypræa staphylæa* LINNÉ.—Tateyama, Satonomisaki, Takanoshima, Pacific and Indian Ocean.
- Cypræa hulvola* L.—Awa (or Bōshu), Formosa, Ogasawarajima, Nijima, Indian Ocean.
- Cypræa flaveola* L.—Awa (or Bōshu), Formosa, Australia.
- Cyclostrema micans* A. AD.—Tōkyō Bay, Inland Sea, Singapore, Australia.
- * *Cerithium kochii* PML.—Misaki, Banda, Kominato, Katanoura, Tango, Nagasaki, China, Port Jackson, Van Dieman's Is., E. coast of Africa.
- Clementia papyracea* GRAY.—Tateyama, New Holland, Molucca, Australia, (Torres Straight, Moreton Bay &c.).
- Cardita variegata* BRUG.—Yokohama, Hongkong, Cape of Good Hope to Indian Ocean.
- Cardium apertum* CHEM.—Tōkyō Bay, Hongkong, Luzon, East Coast of the Philippines.
- * *Cardium muticum* RYE.—Tōkyō, Nagasaki, E. coast of Luzon, East Indies.
- * *Cytherea meretrix* L.—Tōkyō, Awa (or Bōshu), Misaki, Yokohama, Higo, Fushiki, Hakodate, Naruto, Nagasaki, Kuwana, Gōnoura, Kagoshima, Riukiu, Formosa, East Indies, Canton River, Tehifu, North China, Siam, Philippines, Singapore, Amboina, Ceram, Teminber Is., Molucca, Nicobar, Ceylon, Mazatlan, Singhai, Hongkong, Labuan, Java.
- Donax bicolor* GMEL.—Yokohama, Nagasaki, Negro Is., Zanzibar.
- Donax australis* LAM.—Awa (or Bōshu), Australia.
- Donax dysoni* DESH.—Tōkyō Bay, Yokohama, Nagasaki, Siam, Indian Ocean.
- * *Dolium leuteostomum* KÜNSTER.—Tōkyō, Misaki, Nagasaki, Awa, Hakodate, Satsuma, Indian Ocean.
- * *Dentalium octogonum* LAMK.—Tōkyō, Enoshima, Kii, Nagasaki, Hakodate, China, Ceylon.

Erato lachryma GRAY.—Tōkyo, Kamakura, Australia.

Eulima cumingii SOW.—Tōkyo, Sandwich Is., Lord Hood's and Viti Is.

Eulima bilincata AD. and RVE.—Tōkyo, Uruga, Setouchi, Sooloo Sea.

Fissurella sinensis A. AD.—Awa (or Bōshu), Tabu-shima, China Sea, Singapore.

* *Hemifusus ternatanus* GMEL.—Tōkyo, Yokohama to Kii, Indian Ocean, Philippines.

Hipponyx pilosus DESH.—Yokohama, Nagasaki, Natal Coast, Cape of Good Hope, Loanda, Guadeloupe, Mazatlan, Galapagos, Polynesia.

Haliotis grunneri PHIL.—Tōkyo, Nagasaki, China, Australia.

Ianthina globosa SWAINS.—Tōkyo Bay, Mazatlan, Mauritius, Atlantic Ocean, Mediterranean Sea.

Latirus polygonus GMEL.—Tateyama, Ticao Is., Mascarene Is., Central Pacific, Red Sea.

Littorina malaccana PHIL.—Tōkyo, Philippines.

Lyria nucleus LAM.—Tateyama, Okinoshima, N.E. Australia.

Leucozonia smargdula LINNÉ.—Yokohama, Philippines, Viti Is.

Lithodomus curtus LIS.—Tōkyo Bay, Misaki, Madrepore, China Sea.

Murex sinensis RVE.—Tōkyo, Tateyama, Nagasaki, China, Indian Ocean.

Murex adustus LAM.—Tateyama, Tsushima, Ōshima, Philippines, Indian Ocean.

Murex speciosus A. AD.—Yokohama, Seneganbia.

Magilus rostratus A. AD.—Tōkyo Bay, Kino-Ōshima, Madrepore, Red Sea, Bourbon Is.

Macoma truncata JONAS.—Tōkyo Bay, Red Sea, Philippines.

Mytilus atratus LISCHKE.—Tōkyo Bay, South Coast of Ise, Nagasaki, China, Port Jackson in Australia.

Modiola nitida HANLEY.—Tōkyo Bay, Inland Sea, Port Essington in Australia.

Modiola arcuatula HANLEY.—Tōkyo Bay, Singapore, Philippines, Java, Malacca.

Nassa suturalis LAM.—Yokohama, Philippines, Australia, New Caledonia.

Nassa papillosa L.—Yokohama, Central Polynesia, Philippines.

Nassa gemmulata LAM.—Tōkyo Bay, Kii, Goza Harbour, Kagoshima, Philippines, Sunda Strait.

* *Nassa livescens* PHIL.—Tōkyo, Nagasaki, China Sea, Manila, Java.

Nassa dominula TAP.—Yokohama, Gotō Is., East Indies.

Natica povisianus RECL.—Yokohama, Nagasaki, China, Moluccas.

Natica collicii RECL.—Tōkyo, Nagasaki, Hakodate, Australia.

- Natica mamilla* LINN.—Tōkyo Bay, East Indies, Philippines, New Caledonia, Central Polynesia.
- Nerita adspersa* REC.—Tōkyo, East Indies to Central Pacific.
- Nerita crepidularia* LAM.—Tōkyo Bay, Yokohama, China, Philippines, Indian Ocean, India to Malayan Archipelago, New Caledonia.
- Oliva fulgurata* AD. and RVE.—Tōkyo, Yamada Harb., Kamakura, Nagasaki, N. Coast of Tango, China Sea, Philippines.
- Ostrea folium* GM.—Misaki, Wakayama, Indian Ocean.
- Ostrea cucullata* BORN.—Yokohama, E. Coast of Sagami, Misaki, Nagasaki, Nicobar, Ceylon, Natal Coast, Indian Ocean.
- Ostrea plicata* CHEM.—Misaki, Kii, West Indies.
- Pleurotoma unedo* VAL.—Tōkyo Bay, Misaki, Nagasaki, East Indies, Indian Ocean.
- Pleurotoma tuberculata* GRAY.—Tōkyo Bay, Hongkong, Java, Australia.
- * *Pleurotoma oxytropis* SOW.—Tōkyo, Sagami, Ōshima, Mauritius, Panama to Gulf of California.
- Pleurotoma gracilentia* RVE.—Tōkyo, Kamakura, E. Coast of Kii, Philippines, N. Australia.
- Peristernia pulchra* RVE.—Kominato in Awa (or Bōshu), Philippines, Indian Ocean, Red Sea.
- Purpura alveolata* RVE.—Awa (or Bōshu), Kamakura, Oki Is., Seta Coast, Ōshima, Nagasaki, Philippines, Zanzibar, Paumotu, Muscat Bay, Indian Ocean.
- Pyrrula reticulata* LAM.—Tōkyo, Nagasaki, Kuroshima, Matsuenohama, E. Indies, Indian Ocean.
- * *Potamides fluviatilis* PORT. and MICU.—Tōkyo Bay, Nagasaki, China, Hongkong, Philippines, Singapore, Borneo, Australia, Mergui, India.
- Pyramidella pulchella* A. AD.—Tōkyo Bay, Goza Harbour, Mososeki, Red Sea.
- * *Patella amussitata* RVE.—Enoshima, Kii, Fukushimaura in Tosa, Bonin Is., China, Chifu, Philippines.
- Patella stellaeformis* RVE.—Tōkyo, Tsushima, Japan to Port Jackson, S. Australia, Eastwards to Viti Cook's and Society Archipelago.
- Pecten plica* LINNÉ.—Misaki, Takashima, Nagasaki, Ceylon, China Sea.
- Pecten subpricatus* SOW.—Misaki, Shima, Kagoshima, Philippines.
- Pecten squamatus* Gmel.—Tōkyo Bay, Sagami Sea, Zebu Is., Philippines.
- Pecten irregularis* SOW.—Banda and Nemoto in Awa (or Bōshu), Takashima, East Indies.
- Pinna nigrina* LAM.—Tōkyo, Ōshima (Ōsumi), Philippines, Red Sea.
- Rapana bulbosa* SOL.—Yokohama, China, Philippines.
- Rissoina subfuniculata* NEW.—near Kachiyama in Awa (or Bōshu), Persian Gulf to Singapore.

- * *Rapana bezoar* L.—Tōkyo, Yokohama, Misaki, Shimoda, Hakodate, Ise, Kōbe, Higo, Nagasaki, Kagoshima, China, Philippines.
- Siphonalia himmulus* AD. and RYE.—Tateyama, Tsu-saki, Sooloo Sea.
- Strombus aratrum* MART.—Tōkyo Bay, Society Is., Australia.
- Strombus succinctus* L. var. *robustus* SOW.—Tateyama, Okino-Ōshima, Hongkong, Philippines, Indian Ocean.
- Strombus luhuanus* LINNÉ.—Tōkyo, Nagasaki, Takamoshima, Tango, New Caledonia, Philippines, West Coast of Australia, Port Jackson, N. S. Wales, Port Dorey in New Guinea, Molucca, Java, Bourbon Is.
- Siliquaria cumingii* MORCH.—Tōkyo Bay, Nemoto in Awa (or Bōshu), Philippines.
- Siliquaria australis* QUOY.—Tōkyo, Nemoto in Awa (or Bōshu), Australia.
- Sigaretus undulatus* LAS.—Tōkyo, Yokohama, China, Strait of Malacca.
- * *Sigaretus papilla* GMEL.—Tōkyo Bay, Yokohama, Nagasaki, Okino-shima in Kii, Nijima, China, Chifu, Philippines, Tranquebar, Molucca, Negro Is., Red Sea.
- Scalaria aculeata* SOW.—Tōkyo Bay, Tsushima, Hongkong, Malacca, Philippines.
- Scalaria trifasciata* de HAAN.—Tōkyo, Yokohama, Singapore, Philippines.
- Scalaria latifasciata* SOW.—Tōkyo, Mauritius.
- * *Scalaria acuminata* SOW.—Tōkyo Bay, Chifu, Malacca.
- Scalaria immaculata* SOW.—Tōkyo Bay, Luzon.
- Scalaria sulcata* SOW.—Tōkyo Bay, Luzon and Catuanuam in Philippines.
- Scalaria lamellosa* LAM.—Yokohama, Kamakura, Mediterranean Sea, W. Indies, Sandwich Is., Mauritius.
- Stomatia rubra* LAM.—Tōkyo Bay, Setouchi, Korean Strait, Philippines.
- Smetta excavata* HANLEY.—Tōkyo Bay, Kyushū, Satonomisaki, Kuroshima, Hakodate, Yokohama, Kamakura, New Holland, S. Australia.
- Terebra polygyrata* DESHAY.—Tōkyo, Kamakura, Goza Harbour, Izu, Kii, Philippines.
- Terebra strigillata* LINNÉ.—Nemoto in Awa (or Bōshu), Kamakura, Nagasaki, Polynesia, Sandwich Is.
- * *Triton saulie* RYE.—Tōkyo, Misaki, Hitachi, Tateyama, Awaji, Nagasaki, Tsusaki, Setouchi, Luzon, Mauritius, Natal, Galapagos, Matnog.
- Triton costatus* BORX.—Tōkyo, Tateyama in Awa (or Bōshu), Nagasaki, Ōshima, Atlantic Coast of Europe and Africa, Canary and Cape Verde Is., St. Helena, W. Indies to Brazil, Polynesia, Australia, New Zealand, Tahiti, Cape of Good Hope.
- Triton moritinctum* RYE.—Tateyama, W. Indies, Philippines.
- Terebellum terebellum* LINNÉ.—Tōkyo Bay, Nagasaki, Yobuko, Philippines, Australia, New Guinea, Viti Is.

- * *Turbo granulatus* GMEL.—Enoshima, Nagasaki, Kii, Shima, China Sea, Nicobar.
- Tellina vulsella* CHEM.—Tōkyo Bay, Kyushū, Zebu Is. in Philippines, Amboina, Ceylon, E. Coast of Africa, Sechelisien.
- Tellina pulcherrima* SOW.—Tōkyo Bay, Singapore, Banka Strait.
- Tellina rhomboides* Q. and G.—Tōkyo Bay, Philippines, Marianen.
- Tapes variegatus* HANLEY.—Tōkyo, Nagasaki, Oki, Tsushima, Philippines, Coast of New Holland.
- * *Venus foliacea* CHEM.—Tōkyo Bay, Madagascar, Red Sea.
- Venerupis monstrosa* CHEM.—Tōkyo Bay, Tsushima, Kino-Ōshima, Philippines, Nicobar.
- Xenophora pallidula* RVE.—Tōkyo Bay, Ceylon.

(B) Arctic species: (13 sp.)

- * *Cardium californiense* DESH.—Tōkyo, Hakodate, Nagasaki, Etrof, Castries Bay, West Coast of Sakhalin, Behring Sea, Sitcha, Vancouver Is., Fucan Strait, Puget-Sound, Ochotsk Sea, Unalashka, Fusca Strait to Monterey.
- Cardium groenlandicum* CHEM.—Misaki, Arctic Seas of America, Asia and Europa.
- * *Cytherea chinensis* CHEM.—Sagami, Kii, Nagasaki, Hakodate, Kitami, West and East Coast of Sakhalin, China, New Holland, Dui and Ssa-Kato, Castries Bay.
- Hiatula nuttari* CONRAD.—Tōkyo Bay, Hakodate, Etrof.
- * *Maetra sulcataria* DESH.—Tōkyo, Nagasaki, Hakodate, North China, Kurile Sea at the East Coast of Sakhalin, Coast opposite Possjet Bay.
- * *Macoma nasula* CONRAD.—Tōkyo, Misaki, Hakodate, Kamtschatka, Behring Sea, Sitcha, South Coast of Ochotsk Bay, Esquimalt Harbour, West Coast of North America from the northern limit to Vancouver, Oregon, Monterey, California.
- * *Natica clausa* DESH.—Tōkyo, Banda in Awa (or Bōshu), Chōshi, Hakodate, Nemuro, Otaru, Sakhalin, Kamtschatka, Kadjak, Ochotsk Sea, Schlanter Is., Kowajasemlja, Sitka, Melville Is., Vancouver, Eastport, Greenland, Atlantic Ocean southwards to Massachusetts, Lapland, Portugal, Arctic Europe.
- Placunanomia macroschisma* DESH.—Tōkyo, Hakodate, Kamtschaka, Ochotsk.
- Pecten yessensis* JAY.—Tōkyo, Hakodate, Castries Bay, West Coast of Sakhalin.

Pecten vitreus CHEM.—Yokohama, Norway, Greenland.

Triton oregonensis RED.—Tōkyo Bay, Hakodate, Aniwa Bay, Okusiri, Magellan Strait (Chili), Alaska, Oregon.

* *Tressus nuttali* CONRAD.—Tōkyo, Hakodate, Sitcha, along West Coast of America from 34° N. to 58° N.

* *Yoldia lanceolata* SOW.—Enoshima, Hakodate, Nova Zembla, Jenissei, Iceland, Metschigmen Bay, Nytschigane Point in Behring Sea, Puget Sound, Avatscha Bay, Seniavin Strait.

(C) Species chiefly found only in Japan : (164 sp.)

I. Species found chiefly south of Tōkyo.

Alcyonella ocellata A. AD.—Tateyama and Nemoto in Awa (or Bōshū), off Talenshima.

Arca obtusa RVE.—Tōkyo, Misaki, Nagasaki, Setouchi.

Arca ambigua RVE.—Yokohama, Nagasaki.

Bela pyrrha WATSON.—Yokohama, Kōbe.

Aemæa heroldi DKR.—Awa (or Bōshū), Enoshima, Sagami, Nagasaki.

* *Aemæa conulus* DKR.—Yokohama, Tōkyo, Enoshima, Nagasaki.

* *Cancellaria nodulifera* SOW.—Yokohama, Kino-Ōshima, Shimizu.

Cantharus undulata SCHER.—Kominato in Awa (or Bōshū), N. Shore of Tango.

Columbella pumila DKR.—Tōkyo, Kamakura, Nagasaki.

* *Columbella martensii* LKE.—Tōkyo, Enoshima, Nagasaki.

Columbella compta L.—Tōkyo, Kamakura, Nagasaki.

Cassia japonica RVE.—Tateyama, Tsusaki, Nagasaki.

Calliostoma argenteonitens LIS.—Tōkyo, Setouchi.

Calliostoma consors LIS.—Tōkyo Bay, Setouchi.

Cyclostrema dunkeri TRYON.—Tōkyo, Nagasaki.

Corbula erythron LAM.—Tōkyo, Yokohama, Kii, Nagasaki.

Cytherea lasoria CHEMN.—East Coast from Tōkyo to Izumi, Nagasaki, China Sea.

* *Cyclina chinensis* CHEMN.—Tōkyo, Yokohama, Misaki, Nagasaki, Shima, Higo, Kagoshima, Tsushima, Ise, Formosa, Shanghai, Hongkong, East Coast of Cochin China.

Cardita cumingiana DKR.—Tōkyo, Yokohama, Nagasaki, Riukiu

Dolium zonatum GRUN.—South of Tōkyo Bay, Nagasaki, China.

* *Erato callosa* AD. and RVE.—Tōkyo Bay, Nagasaki, China Sea.

* *Fusus nodoso-plicatus* DKR.—Yokohama, Misaki, Nagasaki, Ukushima, Gotō Is., Sumoto, Moji, Tomonotsu.

Hiatura olivacea JAY.—Tōkyo Bay, Nagasaki, near Sakai, Setouchi, Chifu.

Imperator hamatragus MKE.—Tōkyo, Nagasaki, Setouchi.

Lyilia cassidula RVE.—Nemoto in Awa (or Bōshu), Nagasaki, Kino-Ōshima, Tsusaki, Satanomisaki, N. Coast of Tango.

Lima dunkeri SMITH.—Awa (or Bōshu), Misaki, Shima.

Lima lima LINNÉ.—Yokohama, Nagasaki.

Murex emarginata SOW.—Awa (or Bōshu), off Gotō Is.

* *Mactra veneriformis* DESH.—Tōkyo Bay, Higo, Nagasaki, Kii, Kagoshima, Chifu.

Modiola senhausii RVE.—near Enoshima, Tōkyo Bay, Nagasaki, Bizen, Chusan, Chifu.

* *Nassa japonica* A. AD.—Tōkyo, Enoshima, Uruga, Ōshima, Setouchi, Kino-Ōshima, Sado, Izugahara, Goza, Shima.

Nassa fuscolineata E. A. SMITH.—Tōkyo, Cape Shima, N. Shore of Tango.

* *Natica ampla* RVE.—Tōkyo to Enoshima, Awa, Chōshi, Misaki, Henda, Shibo, Kagoshima, Kiire, Nagasaki, Hikata, Uwajima.

* *Nucula mirabilis* HINDS.—Tōkyo Bay, Nagasaki.

* *Ostrea denselanellosa* LIS.—Tōkyo, Awaji, Bungo, South Shikoku, Riukiu.

Philine scalpta A. AD.—Tōkyo Bay, Tsushima, Corean Strait.

Pleurotoma japonica LIS.—Awa (or Bōshu), Kamakura, Tōkyo, Kii, Nagasaki, North Kyushū, Hongkong.

* *Pleurotoma subauriformis* SMITH.—Tōkyo, Kamakura, Setouchi.

Pleurotoma texta DKK.—Tōkyo, Nagasaki.

Pleurotoma costulata DKK.—Tōkyo, Nagasaki.

Pleurotoma leuckarti DKK.—Tōkyo, Kamakura, Deshima.

* *Pyramidella cinctella* AD.—Tōkyo, Ōshima in Izu, Setouchi, Matoza.

Pecten crassicostatus SOW.—Tōkyo, Misaki, Ise, Nagasaki, Kii, Hongkong, Shanghai.

Pecten japonicum GMEL.—Tōkyo, Tateyama in Awa (or Bōshu), Setouchi, Nagasaki, Misaki, Enoura in Suruga, Tateishi in Tosa, Kagoshima, Riukiu, China.

Pinna japonica HANLEY.—Tōkyo, Yokohama, Nagasaki.

Pinna lischkeana CLES.—Yokohama, Tōkyo, Misaki, Okayama, Setouchi.

Siphonalia fusoides RVE.—Tōkyo Bay, Tsushima, Satanomisaki, S. E. Coast of Kii.

Siliqua pulchella DKK.—Tōkyo Bay, between Tōkyo and Ōshima, Kyushū.

Spondylus erenulatus LKE.—Misaki, Kii, Nagasaki.

Tornatella strigosa GLD.—Tōkyo, Goza, Nagasaki, Riukiu, Kagoshima.

Triton excavation RVE.—Tōkyo, Nagasaki.

Triforis fusca DKR.—Tōkyo, Kamakura, Tateyama in Awa (or Bōshu), Nagasaki, North Coast of Tango.

Triforis trilineata DKR.—Tōkyo, Tateyama in Awa (or Bōshu), Kamakura, North Coast of Tango.

Trochus neritoides PHIL.—Yokohama, Southeast Coast of Kii.

* *Trochus japonicus* AD.—Tōkyo, Yokohama, Nemoto in Awa (or Bōshu), Nagasaki, Setouchi, North Coast of Tango.

* *Tellina nitidula* DKR.—Yokohama, Kamakura, Nagasaki.

Tellina rutila DKR.—Yokohama, Nagasaki.

Tellina irridella V. MARTENS.—Tōkyo Bay, Kamakura, Nagasaki.

Tellina prætecta V. MARTENS.—Tōkyo, Yokohama, Nagasaki.

* *Tellina yedensis* LKE.—Tōkyo, Kii.

Tapes melanægis RÖMER.—Tōkyo Bay, Setouchi.

II. Species found chiefly north of Tōkyo.

Dosinia japonica RVE.—Tōkyo, Hakodate.

Glycimeris japonica A. AD.—Tōkyo Bay, Hakodate.

Modiola japonica DKR.—Tōkyo Bay, Hakodate.

* *Nucula insignis* GLD.—Tōkyo, Hakodate.

* *Volutharpa perryi* JAY.—Tōkyo, Enoshima, Hakodate.

III. Species found both north and south of Tōkyo.

Acmaea schrenckii LKE.—Yokohama, Nagasaki, Ojima, Hakodate.

Anomia laqueata RVE.—Tōkyo, Misaki, off Kōbe, Hakodate.

* *Area inflata* RVE.—Tōkyo Bay, Nagasaki, Hakodate, East Coast of Hokkaido (also in Tartarei, Kingsmill Is., Philippines).

Columbella varians DKR.—Tōkyo, Kamakura, Yokohama, Hakodate, N. Shore of Tango, Rifunsiri.

* *Eburna japonica* SOW.—Tōkyo, Tateyama, Misaki, Enoshima, Izu, Hakodate, Ōshima, Kamakura, Tsusaki, Echizen, Sado, Nagasaki, Higo, Fukuoka, Awa, Shimonoseki.

* *Fusus perplexus* A. AD.—Tōkyo, Nagasaki, Sagami Bay, near Gotō Is., Hakodate, Tsushima, Moji in Hizen.

Hemifusus tuba GMEL.—Tateyama, Nagasaki, Hakodate, Tsushima, China.

Haliotis gigantea GMEL.—Tōkyo, Nagasaki, Kii, Kamakura, Hakodate.

* *Leda confusa* HANLEY.—Enoshima, Hakodate, China Sea, Tōkyo.

* *Limopsis woodwardi* A. AD. (?)—Japan.

Mya arenaria var. *japonica* JAY.—Tōkyo, Nagasaki, Hakodate.

- * *Macha divaricata* LKE.—Enoshima, Misaki, Hakodate, Wakanoura, Nagasaki, Setouchi.
- Nassa fraterculus* DKR.—Tōkyo, Ise, Kamakura, Gotō, Tateyama, Hakodate, Simoda, Nagasaki, Deshima.
- * *Ostrea gigas* THUNB.—Yokohama, Nagasaki, Chōshi, Rikuzen, North China, Talienwan, Chifu.
- Olivella consobrina* LKE.—Tōkyo, Enoshima, Kamakura, Hakodate, Yamada, Nagasaki, N. Coast of Tango.
- Purpura luteostoma* DILLW.—Tōkyo, Hakodate, Nagasaki, Seta Coast, Suruga, Riukiu.
- * *Pleurotoma principalis* PILSBRY.—Enoshima, Noto, Setouchi, Kii.
- * *Potamides zonale* BRUG.—Tōkyo, Yokohama, Hakodate, Matsushima, Ōshima, Fla, Hongkong.
- Patella toreuma* RYE.—Banda in Awa (or Bōshu), Enoshima, Nagasaki, Hakodate, China.
- * *Pecten latus* GLD.—Tōkyo, Hakodate, Sagami Bay, Ikai, Nagasaki, Yokohama, Chōshi.
- * *Pecten laqueatus* SOW.—Tōkyo, Awa (or Bōshu), Misaki, Bingo, Miyajima, Kii, Awaji, Iki, Iyo, Satsuma, Suruga, Tsushima, Echizen, Chōshi, Riukiu, Kōbe, Nagasaki, Setouchi, California.
- * *Pectunulus albo-lineatus* LKE.—Tōkyo, Kii, Hakodate, Tsushima, Kitami, Fusan, Possjet Bay.
- * *Rotella costata* LESSON.—Enoshima, Hakodate, Izu, Shima, Kii, Hizen, Tsushima, Nagasaki.
- * *Siphonalia cassidareiformis* RYE.—Misaki, Enoshima, Nagasaki, Hakodate, Izu, Gotō Is., Ōshima, Awa.
- * *Solen gouldii* CONRAD.—Enoshima, Misaki, Hakodate, Ise, Nagasaki, China Sea.
- * *Terebra bipartita* GLD.—Enoshima, Hakodate.
- Trochus pfeifferi* PHIL.—Tōkyo, Shimoda. S.E. Coast of Kii, Hakodate.
- Trochus subfuscus* SCHRENCK.—Tōkyo, Hakodate, Ōshima, Endermo.
- * *Trochus imperialis* A. AD.—Tōkyo Bay, Hakodate.
- * *Tornatella gigantea* DKR. (?)—Japan.
- Telina inquinata* DESH.—Tōkyo, Yokohama, Kii, Nagasaki, Hakodate, Fusan, Castries Bay, West Coast of Sakhalin, Ochotsk Sea, Vancouver, Columbia, West Coast of America north or south from Vancouver.
- Tapes vernicosa* GLD.—Tateyama, Kagoshima, off Hakodate.
- * *Trochus argyrostomus* GMEL.—Tōkyo, Kii, Hakodate, Possjet Bay, China, Port Hamilton (Corea), Formosa, Philippines.
- Voluta megaspire* SOW.—Tōkyo Bay, Setouchi, Hakodate.

IV. Species found only near Tōkyō.

Anatina japonica LKE.—Tōkyō, Yokohama.

Anomia cytarau GRAY.—Misaki.

Arca satowi DKE.—Tōkyō.

Buccinum leucostoma LKE.—Tōkyō Bay, Yokohama.

Conus sieboldi RYE. (?)—Tōkyō Bay, China.

Cancellaria bocageana CROOSSE and DAB. (?)—Tōkyō Bay, China.

Cyclostrema duplicata LKE.—Tōkyō.

Cardilia semisulcata DESH.—Tōkyō Bay.

Cultellus cultellus LINNÉ.—Tōkyō Bay.

Dentalium yokohamense WATSON.—Yokohama.

Dosinia bilunulata GRAY.—Tōkyō Bay, Yokohama, Sagami Coast.

Dosinia trailli A. AD.—Yokohama.

Dosinia gibba A. AD.—Tateyama.

Cyrelina orientalis SOW.—Yokohama.

Cypriocardia lirata RYE.—Tōkyō Bay, Awa (or Bōshū).

Fissurella dilatata A. AD.—Nemoto in Awa (or Bōshū).

* *Fissurella lischkei* PILSBRY.—Nemoto in Awa (or Bōshū).

Fissuridea sieboldii RYE.—Tōkyō Bay.

Gari oruata DESH.—Tōkyō Bay.

Gari bipartita PHIL.—Tōkyō Bay.

Gastrana japonica V. MARTENS.—Yokohama.

Hiatula atrata DESH.—Tōkyō.

Lacuna oxytropis PILSBRY.—Tōkyō.

Lacuna stenotomorpha PILSBRY.—Tōkyō.

Lucinopsis divaricata LKE.—Tōkyō.

Lucina contraria DKE.—Tōkyō.

Lepton subrotundum DKE.—Tōkyō.

Lima japonica A. AD.—3 miles off Jōgashima (Misaki).

Limopsis pelagica E. A. SMITH.—Yokohama, Enoshima.

Lingula anatina BRUG.—Tōkyō, Enoshima.

* *Mactra crossei* DKE.—Tōkyō.

Modiola philippinarum HANLEY.—Nemoto in Awa (or Bōshū).

Modiolaria semigranata RYE.—Tōkyō.

Philine japonica LKE.—Tōkyō Bay, Yokohama.

Oliva signata L. (?)—Tōkyō, Awa, China.

Pleurotoma patruelis SMITH. (?)—Tōkyō Bay, Japan Sea.

Pleurotoma ludhorfi LKE.—Tōkyō Bay, Nemoto in Awa (or Bōshū).

Pleurotoma tokyensis PILSBRY.—Tōkyō, Kamakura.

*Pleurotoma mahimono*s JOUSS.—neighborhood of Tōkyō Bay.

Pleurotoma kaderleyi LKE.—Tōkyō Bay, Enoshima.

- Potamides multiformis* L.—Tōkyō.
Pyramidella tenuisculpta LKE.—Tōkyō Bay.
Phasianella oligomphala PILSBRY.—Tōkyō, Nemoto in Awa (or Bōshu).
Parapholas punita CONRAD.—Tōkyō.
Pectunculus rotundus DKR.—Tōkyō Bay.
Pyramidella eximia LKE.—Tōkyō, Kamakura.
Rissoina adamsiana WKEF.—Kaehiyama in Awa (or Bōshu).
Reta pulchella AD. and RVE.—Yokohama.
Reta yokohamensis PILSBRY.—Yokohama.
Separatista separatista DILLY.—Nemoto in Awa (or Bōshu).
Sigaretus japonicus LKE.—Tōkyō.
Scalaria casta A. AD.—Tōkyō, Yokohama, Kamakura.
Terebra bathyrhapha SMITH.—Tōkyō Bay.
Triton dorsuosum AD.—Tateyama in Awa (or Bōshu).
Turbo guttatus A. AD.—Tateyama in Awa (or Bōshu).
Trochus yokohamensis PILSBRY.—Yokohama.
Trochus japonica SMITH.—Tōkyō Bay.
Trochus pauperculus L.—Tōkyō.
Tellina ovalis SOW.—Tōkyō.
Tapes undulatus BORN.—Tōkyō Bay, Tateyama in Awa (or Bōshu).
Vermetus tokyōensis PILSBRY.—Tōkyō.
Venerupis purpurea DKR.—Nemoto in Awa (or Bōshu).
Yoldia lischkei E. A. SMITH.—Yokohama, Enoshima.
Tellina minuta LKE.—Tōkyō Bay.
Venus yedōensis LKE.—Kamakura, Tōkyō Bay.

V. Species found in Tōkyō and elsewhere very widely distributed.

- * *Saxicava arctica* DESH.—Tōkyō, Noto, Awa, Ōsaka, Hakodate, North-eastern and Northern Sea of Asia, Western Coast of America, Europe, Africa, Indian Ocean, Australia.
- * *Saxidomus nuttali* CONRAD.—Tōkyō, Misaki, Enoshima, Hakodate, Harima, Setouchi, Bonin Is., Kamtschatska, Sitcha, India, Chile, California.
- * *Dosinia exoleta* LINN.—Tōkyō, Hakodate, Misaki, Kii, Setouchi, Chifu, North China, Spain, France, Piedmont, Corsica, Naples, Tarent, Sicily, Ustria, Adria-Zara, Venedig, Morea, Tunis, Algeria, Balearen, Norway, Great Britain, Portugal, Mediterranean Sea, from North Cape (72° N.) to Senegal (15° N).
- * *Tapes decussata* DKR.—Tōkyō, Hakodate, Kitami, Enoshima, Misaki, Nagasaki, Rikuzen, Ōshima, West Coast of Sakhalin, Olga Bay,

Rifusiri, Korea, Possjet Bay, Castries Bay, Cape Notoro, Cape Tofuts, Formosa, Singapore, China, East Indies, New Zealand, Java, Amboina, Egypt, Britain, Mediterranean, France, Pyreneese Peninsula.

* *Modiola modiolus* LINN.—Tōkyō, Hakodate, Setouchi, Behring Sea, Lapland in Russia, entire North Atlantic Coast of Europe and America, and New England in America, Mediterranean Sea.

As may be seen from the above list, in which species marked with asterisks are those found also in our fossil localities, the number of tropical forms found living and in the fossil state is quite small. The tropical living species amount to 39% of the whole, while the arctic amount to 4%, and those found only in Japan to 55%. But the percentage in our fossil forms is as follows :

Tropical species	22 %
Arctic species	15 %

It is quite interesting to observe that, while the proportion of the arctic to tropical species in the list of the above living fauna is 1 : 9.75, that of the fossils is 1 : 1.46.

Among the fossil forms, the following are not found in the environs of Tōkyō :—

Neptunea despecta LINNÉ.—*Buccinum undatum* LINNÉ.—*Natica clausa* DESH.—*Panopæa generosa* GLD.—*Macra sachalinensis* SCHRENCK.—*Venus stimpsoni* GLD.—*Tapes rigidus* GLD.—*Astarte japonica* TOK.—*Tapes cuglyptus* PH.—*Martesia striata* LINNÉ.—*Lucina borealis* L.

These species are never found in tropical regions, and the first eight species are restricted to arctic fauna. From this we see that the sea near Tōkyō was formerly inhabited by univalves and bivalves of a climate colder than that which prevails at present.

Next let us consider the question of the geological age of our fossil beds. BRAUNS assumed the existence of a line of unconformability between the shell bed and the Diluvium above it, and identified many of the shells with those of the English

Crag, although he recognized no extinct species in his collection. The result obtained by myself is slightly different. Before stating it, however, it is necessary first to examine whether the fossil beds represent a single geological horizon or not. Fig. 2

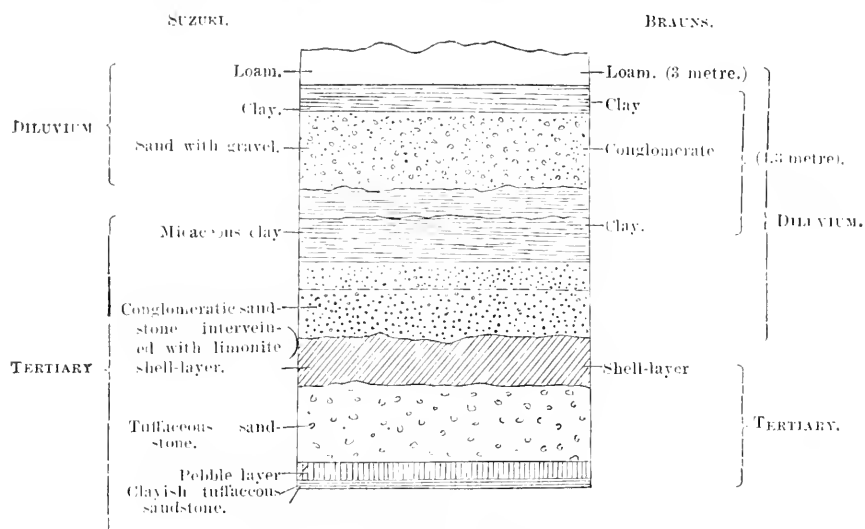


Fig. 2.—Profile at Ōji fossil bed.

shows the order of succession of the layers at Ōji as observed by BRAUNS and Dr. T. SUZUKI. The boundary line between the Tertiary and Quaternary is assumed by BRAUNS to be directly above the shell layer, while SUZUKI takes for it a micaceous clay, in which badly preserved plant impressions were discovered. Of this line in the layers of Shinagawa SUZUKI makes no precise statement in his "Explanatory Text to the Geological Sheet, Tōkyō, 1887," (published in Japanese). As shown in my profile (Fig. 3), a bluish clay and sand are overlaid by a brownish clay, and are found above the shell layer which cor-

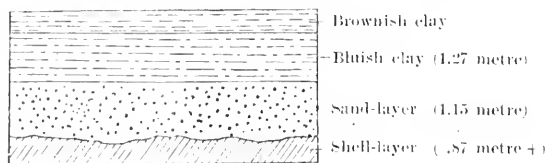


Fig. 3.—Profile at Shinagawa fossil bed.

responds to that of Ōji. This brownish clay contains plant leaves like those found in the corresponding clay at Ōji. A fossil locality of Tabata, a place situated between Ōji and Tōkyō, lies at the foot of a plateau which is a southern continuation of that of Ōji. Some years ago a good geological profile was exposed by a cutting made for railway purposes. The brownish and bluish clay layers at the bottom of my profile (Fig. 4) contain different

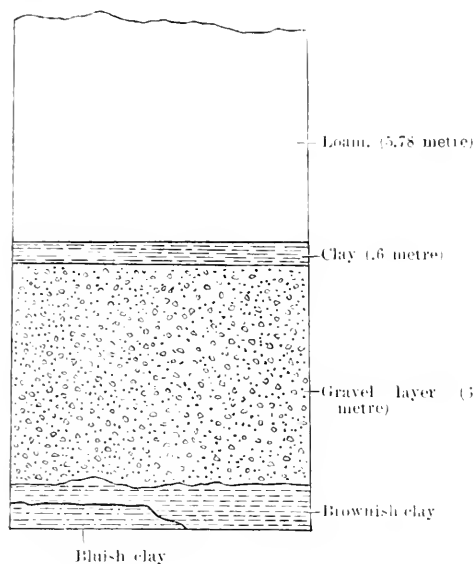


Fig. 4.—Profile at Tabata fossil bed.

kinds of fossils at different parts even of the same horizon. In some parts we find numerous plant leaves, while in others trunks of trees and shells. Where the shells are numerous, the clay passes into sands. These clay layers must represent those of the plant bearing clay of Ōji and Shinagawa. The fossil layer of Surugadai, whence BRAUNS obtained some of his specimens,

is at present not accessible on account of the considerable weathering of the rock surface. But it is almost certain that it is a continuation of the shell-bed of Tabata, the geological profile being the same in both localities, and most of the shells collected by BRAUNS belong to those forms which are found at Tabata. In the three profiles above mentioned, the uppermost part which consists of loam with underlying gravel is decidedly diluvial. Below the gravel lie brownish and bluish clays which are represented partly by a shell-bearing sand, as at Tabata.

In the brownish clay of Ōji and Shinagawa, plant leaves rarely occur, while at Tabata the brownish as well as the bluish clay contains great quantities of them. Below the clays is found a bluish sand, which yields some molluscan casts* at Shinagawa and Ōji and numerous shells at Tabata. At the last locality no bed lower than this sand is exposed. But at Shinagawa and Ōji, there is a sand with numerous shells, showing a wavy line of boundary against the overlying sand on natural profiles.

BRAUNS regarded this wavy line as an important demarcation between his “non-fossiliferous zone” (in reality containing shell casts at Ōji and Shinagawa) and the underlying shell bed. However, as is well known, the surface of shell heaps constantly disturbed by sea waves is usually not perfectly flat and horizontal, but shows numerous depressions and elevations. The same thing is also observable in strata, for instance in those of the Tertiary of Sendai, Province of Rikuzen, where there are three shell zones in a thick tufaceous sandstone, each shows a wavy surface. On the eastern side of a railway cutting at Shinagawa, the line is not always distinct, and the overlying sand, which does not differ from the shell bed either in colour or hardness, sometimes contains shells irregularly pushed in from the lower bed. From the above facts it will be seen that the so-called line of demarcation is not of any great significance in the determination† of the age of the shell-bed.

The bluish clay overlying the sand is to be considered as belonging to the same geological epoch as the latter, for in some places the clay alters its nature according to the sand,

* Casts found at Ōji and Shinagawa belong to *Aren. inflata* RYE., *Pecten laqueatus* SOW., *Pectunculus albo-lineatus* LKE., *Panopaea generosa* GLD., *Saxidomus nuttali* CONRAD, *Tapes rigidus* GLD. and *Alacoma nasuta* CONRAD, &c.

† It must be kept in mind that the layers now under discussion lie almost horizontally.

so that these two form a single bed as is seen on the western side of the Shinagawa railway cutting and also at Tabata. Next relating to this bluish clay and the overlying brownish one, the difference of colour is quite unimportant, the line of boundary between them being very irregular at Tabata as shown in the figure 5. The

insignificance of this line is also shown by a regular horizontal pebbly layer traversed by it. So the



Fig. 5.—Profile showing the boundary line between brownish and bluish clay at Tabata.

brown color of clay will be only the result of oxidation caused by the action of percolating water.

So if indeed any geological gap exists in our profiles, it must be found high up between the brownish clay and the gravel layer and not lower down. BRAUNS determined the age of our fossil beds to be Pliocene by identifying their mollusks chiefly with those of the Crag. But it very seldom happens that non-pelagic species, either Recent or Pliocene, show so wide a distribution as to be found in Japan and Europe at the same time. No recent Japanese shells, excepting a few, which are mostly cosmopolitan, pass the Red Sea on the one side or the west coast of America on the other. Of the twenty-two species described by BRAUNS as identical with those of the Crag, only five are so according to my own determination, and of these four are either cosmopolitan or circumpolar. In BRAUNS' work no extinct species are mentioned; but I recognize about ten* which are considered as surely extinct. Still this

* *Trochus shinagawensis* TOK., *Tellina serripastata* TOK., *Tellina ojiensis* TOK., *Cardium braunsi* TOK., *Cardium rotunda* TOK., *Pecten tkyoensis* TOK., *Mysis pacifica* TOK., &c.

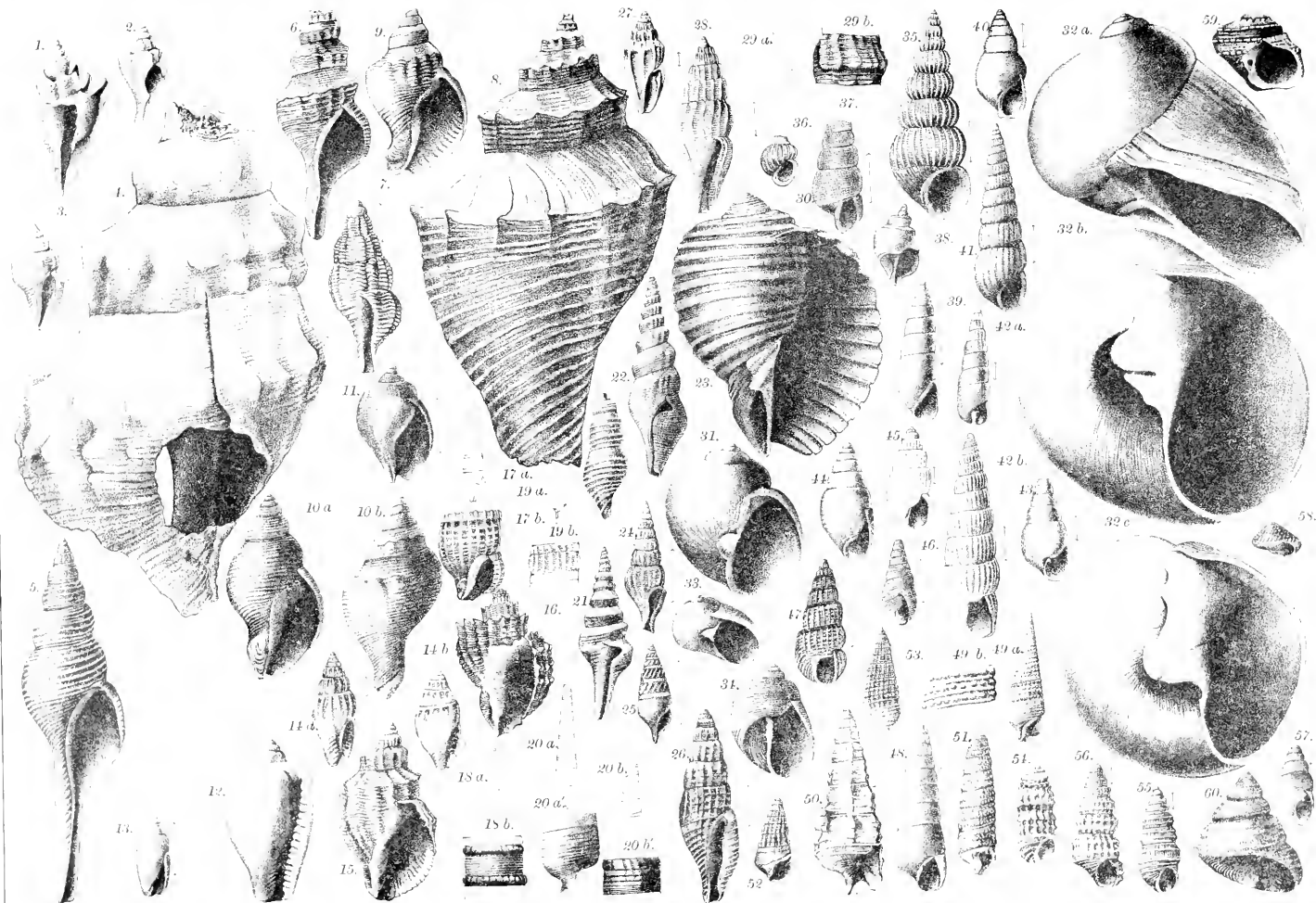
number may be regarded too small to warrant us in assuming the Tertiary age of the fossils. It is also interesting to note that there was a decided diminution of temperature as shown by the predominance of arctic forms in the molluscan fauna. Another feature that leads us to think that our fossil zones may be younger than the Pliocene is the discovery of a tusk, teeth and bone fragments of an elephant from a bed below the shell-layer of Tabata. The specimens belonging to the same species and collected at other places in Japan were determined by NAUMANN as *Elephas namadicus* FALC., which had formerly been restricted to the Post-pliocene of the Narbada series according to BLANFORD,* while BRAUNS, as before mentioned, took them for those of *Elephas antiquus* FALC. and CAUT. This author, moreover, assumed all of the Japanese elephants, including those from Tōkyō, to be Diluvial forms. Therefore I consider the shells formerly taken for Tertiary as belonging to the Diluvial epoch.

* NAUMANN, Ueber Japanische Elephanten der Vorzeit.—Palaeontographica, Bd. XXVIII., Heft I., 1881, p. 24.

PLATE I.

- Fig. 1. *Murex falcatus* SOW. (Nat. size).
Fig. 2. *Murex longicanalis* TOK. (Nat. size).
Fig. 3. *Trophon exiguus* TOK. (Magnified).
Fig. 4. *Triton saulie* L. (Nat. size).
Fig. 5. *Fusus nodoso-plicatus* DKR. (Nat. size).
Fig. 6. *Fusus perplexus* A. AD. (Nat. size).
Fig. 7. *Fusus simplex* E. A. SMITH. (Magnified).
Fig. 8. *Hemifusus ternatanus* GMEL. (Nat. size).
Fig. 9. *Siphonalia cassidularæformis* RVE. (Nat. size).
Figs. 10 *a* and *b*. *Buccinum undatum* LINN. (Nat. size).
Fig. 11. *Volutharpa perryi* JAY. (Magnified).
Fig. 12. *Erato callosa* AD. and RVE. (Magnified).
Fig. 13. *Olivella consobrina* LKE. (Magnified).
Figs. 14 *a* and *b*. *Columbella pumila* DKR. (Magnified).
Fig. 15. *Cancellaria spengleriana* DESH. (Nat. size).
Fig. 16. *Cancellaria nodulifera* SOW. (Nat. size).
Figs. 17 *a* and *b*. *Terebra alveolata* HINDS. (Fig. 17*a* in natural size ; fig. 17*b* magnified).
Figs. 18 *a* and *b*. *Terebra pretiosa* RVE. (Fig. 18*a* in natural size ; fig. 18*b* magnified).
Figs. 19 *a* and *b*. *Terebra subtextilis* E. A. SMITH. (Fig. 19*a* in natural size ; fig. 19*b* magnified).
Figs. 20 *a*, *a'*, *b* and *b'*. *Terebra* CFR. *serotina* AD. and RVE. (Figs. 20*a* and *b* in natural size ; figs. 20 *a'* and *b'* magnified).
Fig. 21. *Pleurotoma oxytropis* SOW. (Nat. size).

- Fig. 22. *Pleurotoma vertebrata* SMITH. (Nat. size).
Fig. 23. *Pleurotoma principalis* PILSBRY. (Nat. size).
Fig. 24. *Pleurotoma sabauriformis* SMITH. (Magnified).
Fig. 25. *Pleurotoma varicostata* SMITH. (Magnified).
Fig. 26. *Pleurotoma gracilentia* RVE. (Magnified).
Fig. 27. *Pleurotoma tabatensis* TOK. (Magnified).
Fig. 28. *Pleurotoma ojiensis* TOK. (Magnified).
Figs. 29 *a* and *b*. *Pleurotoma sagamiensis* TOK. (Fig. 29*a* in natural size ; fig. 29*b* magnified).
Fig. 30. *Dolium leuteostomum* KÜNSTER. (Nat. size).
Fig. 31. *Natica clausa* DESH. (Nat. size).
Figs. 32 *a*, *b* and *c*. *Natica ampla* RVE. (Nat. size).
Fig. 33. *Natica papyracea* BUSH. (Nat. size).
Fig. 34. *Sigaretus papilla* GMEL. (Nat. size).
Fig. 35. *Scalaria immaculata* SOW. (Magnified).
Fig. 36. *Scalaria lamellosa* LAM. (Nat. size).
Fig. 37. *Scalaria acuminata* SOW. (Magnified).
Fig. 38. *Trichotropis unicarinata* BROD. (Nat. size).
Fig. 39. *Eulima levis* TOK. (Magnified).
Fig. 40. *Eulima ovalis* TOK. (Magnified).
Fig. 41. *Turbonilla* AFF. *elegantissima* MONT. (Magnified).
Figs. 42 *a* and *b*. *Turbonilla fusca* A. AD. (Magnified).
Fig. 43. *Odostomia fuscata* DKR. (Magnified).
Fig. 44. *Odostomia* CFR. *subplanata* GLD. (Magnified).
Fig. 45. *Odostomia takinogawensis* TOK. (Magnified).
Fig. 46. *Pyramidella eximia* LKE. (Magnified).
Fig. 47. *Pyramidella spirata* A. AD. (Magnified).
Fig. 48. *Pyramidella cinctella* A. AD. (Magnified).
Figs. 49 *a* and *b*. *Cerithium kochii* PHIL. (Fig. 49*a* in natural size : fig. 49*b* magnified).
Fig. 50. *Cerithium nipponiensis* TOK. (Magnified).
Fig. 51. *Cerithium tabatensis* TOK. (Magnified).
Fig. 52. *Potamides fluviatilis* POT. and MICH. (Nat. size).
Fig. 53. *Potamides incisus* HOMBR. and JACQ. (Nat. size).
Fig. 54. *Rissoa* CFR. *cerithina* PHIL. (Magnified).
Fig. 55. *Rissoa septentrionalis* TOK. (Magnified).
Fig. 56. *Rissoa meridionalis* TOK. (Magnified).
Fig. 57. *Rissoa subcylindrica* TOK. (Magnified).
Fig. 58. *Rotella costata* LESSON, var. *superbus* GLD. (Nat. size).
Fig. 59. *Turbo granulatus* GLD. (Nat. size).
Fig. 60. *Trochus imperialis* A. AD. (Nat. size).



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FOSSILS FROM THE ENVIRONS OF TOKYO.

PLATE II.

Errata.

In the explanation of Plate VI., after “ *All figures in natural size* ” add “ *except Fig. 6 which is in $1\frac{1}{2}$ nat. size.* ”

- Fig. 5. *Trochus angulatus* TOK. (Magnified).
Fig. 6. *Fissurella lischkei* PILSBRY. (Nat. size).
Figs. 7 *a* and *b*. *Acmaea conulus* DKR. (Magnified).
Figs. 8 *a* and *b*. *Patella amussitata* RVE. (Fig. 8*a* in natural size ; fig. 8*b* magnified).
Fig. 9. *Tornatina exilis* DKR. (Magnified).
Fig. 10. *Tornatella gigantea* DKR. (Nat. size).
Fig. 11. *Ringicula arcata* GLD. (Magnified).
Fig. 12. *Cylichna musashiensis* TOK. (Nat. size).

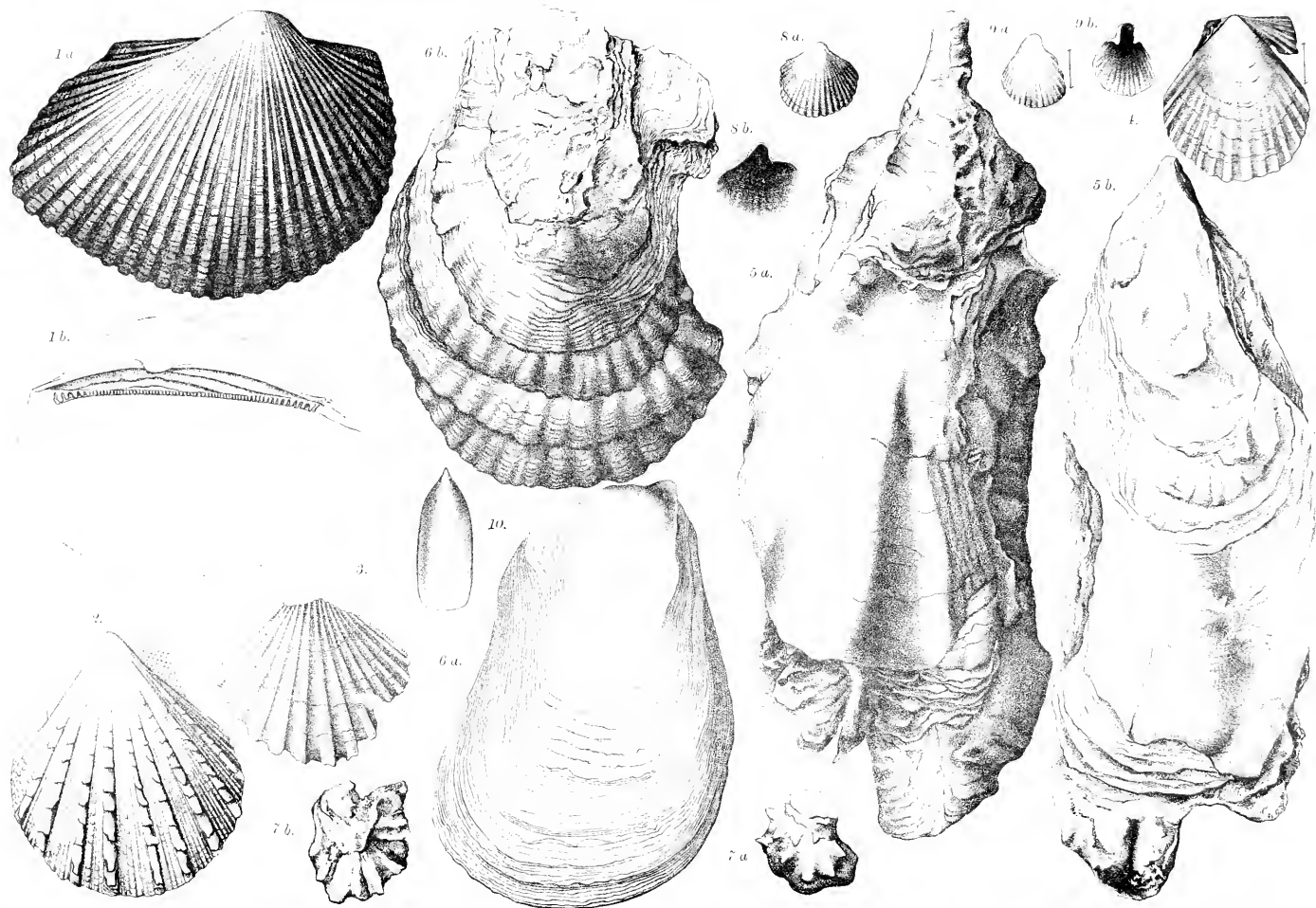
S. TOKUNAGA.

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PLATE II.

- Fig. 1. *Trochus argyrostomus* GMEL. (Nat. size).
Fig. 2. *Trochus amussitatus* GLD. (Magnified).
Fig. 3. *Trochus japonicus* A. AD. (Magnified).
Fig. 4. *Trochus shinagawensis* TOK. (Nat. size).
Fig. 5. *Trochus angulatus* TOK. (Magnified).
Fig. 6. *Fissurella lischkei* PILSBRY. (Nat. size).
Figs. 7 *a* and *b*. *Acmea conulus* DKR. (Magnified).
Figs. 8 *a* and *b*. *Patella amussitata* RVE. (Fig. 8*a* in natural size ; fig. 8*b* magnified).
Fig. 9. *Tornatina exilis* DKR. (Magnified).
Fig. 10. *Tornatella gigantea* DKR. (Nat. size).
Fig. 11. *Ringicula arctata* GLD. (Magnified).
Fig. 12. *Cylichna musashiensis* TOK. (Nat. size).

- Fig. 13. *Cylichna acuta* TOK. (Magnified).
- Fig. 14. *Cylichna obtusa* TOK. (Magnified).
- Figs. 15 *a* and *b*. *Dentalium octogonum* LAMK. (Nat. size).
- Figs. 16 *a* and *b*. *Dentalium weinkauffi* DKR. (Nat. size).
- Fig. 17. *Dentalium edænsis* TOK. (Nat. size).
- Fig. 18. *Martesia striata* LINNÉ. (Nat. size).
- Fig. 19. *Solen krausensternii* SCHRENCK. (Nat. size).
- Figs. 20 *a* and *b*. *Macha divaricata* LKE. (Nat. size).
- Figs. 21 *a* and *b*. *Saxicava arctica* DESH. (Nat. size).
- Figs. 22 *a*, *a'*, *b* and *b'*. *Corbula venusta* GLD. (Figs. 22 *a* and *b* in natural size; figs. 22 *a'* and *b'* magnified).
- Figs. 23 *a* and *b*. *Næerea gouldiana* HINDS. (Magnified).
- Figs. 24 *a* and *b*. *Myodora fluctuosa* GLD. (Nat. size).
- Figs. 25 *a* and *b*. *Macra sachalinensis* SCHRENCK. (Nat. size).
- Figs. 26 *a* and *b*. *Macra sulcatoria* DESH. (Nat. size).
- Figs. 27 *a* and *b*. *Macra crossei* DKR. (Nat. size).
- Figs. 28 *a*, *b* and *c*. *Lutraria ovalis* TOK. (Nat. size).
- Figs. 29 *a*, *b* and *b'*. *Lutraria* sp. (Figs. 29 *a* and *b* in natural size; fig. 29 *b'* magnified).
- Figs. 30 *a*, *a'*, *b* and *b'*. *Tellina nitidula* DKR. (Figs. 30 *a* and *b* in natural size; figs. 30 *a'* and *b'* magnified).
- Figs. 31 *a* and *a'*. *Tellina yedænsis* LKE. (Fig. 31 *a* in natural size; fig. 31 *b* magnified).
- Figs. 32 *a*, *a'* and *b*. *Tellina serricostata* TOK. (Figs. 32 *a* and *b* in natural size; fig. 32 *a'* magnified).
- Figs. 33 *a* and *a'*. *Tellina tenera* SAY. (Figs. 33 *a* in natural size; fig. 33 *a'* magnified).
- Figs. 34 *a*, *a'* and *b*. *Tellina ojiana* TOK. (Figs. 34 *a* and *b* in natural size, fig. 34 *a'* magnified).
- Figs. 35 *a* and *a'*. *Tellina* AFF. *rutile* DKR. (Fig. 35 *a* in natural size; fig. 35 *a'* magnified).
- Figs. 36 *a* and *a'*. *Tellina nipponica* TOK. (Fig. 36 *a* in natural size; fig. 36 *a'* magnified).



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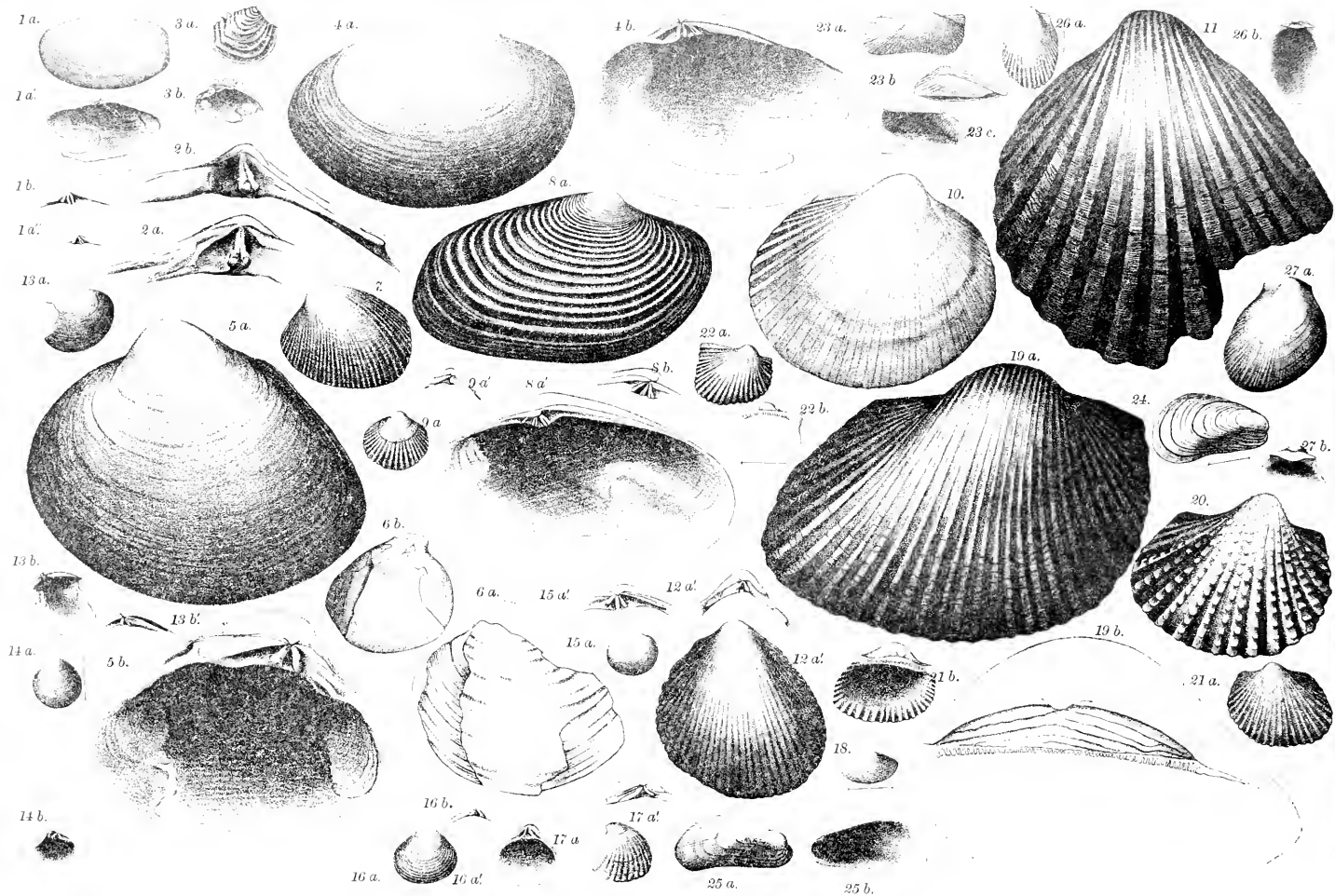
FOSSILS FROM THE ENVIRONS OF TOKYO.

PLATE III.

Plate III.

- Figs. 1 *a*, *a'*, *a''* and *b*. *Gari* cfr. *radiata* DKR.
 Figs. 2 *a* and *b*. *Macoma nasuta* CONRAD.
 Figs. 3 *a* and *b*. *Venus foliacea* PH.
 Figs. 4 *a* and *b*. *Cytherca chinensis* CHEM.
 Figs. 5 *a* and *b*. *Cytherca meretrix* LINNÉ.
 Figs. 6 *a* and *b*. *Clementia* AFF. *papyracea* GRAY.
 Fig. 7. *Tapes decussata* DKR. VAR. *philippinarum* AD. and RVE.
 Figs. 8 *a*, *a'* and *b*. *Tapes euglyptus* PH.
 Figs. 9 *a* and *a'*. *Cardium californiense* DESH.
 Fig. 10. *Cardium muticum* RVE.
 Fig. 11. *Cardium braunsi* TOK.
 Figs. 12 *a* and *a'*. *Cardium tokyoensis* TOK.
 Figs. 13 *a*, *b* and *b'*. *Mysia* AFF. *semiaspera* PHIL.
 Figs. 14 *a* and *b*. *Lasca striata* TOK.
 Figs. 15 *a* and *a'*. *Lasca* AFF. *suborbicularis* MONT.
 Figs. 16 *a*, *a'* and *b*. *Astarte japonica* TOK.
 Figs. 17 *a* and *a'*. *Cardita rotunda* TOK.
 Fig. 18. *Yoldia lanceolata* J. SOW.
 Figs. 19 *a* and *b*. *Arca inflata* RVE.
 Fig. 20. *Arca granosa* LINNÉ.
 Figs. 21 *a* and *b*. *Arca kagoshimensis* TOK.
 Figs. 22 *a* and *b*. *Arca a* SP.
 Figs. 23 *a*, *b* and *b*. *Arca rectangularis* TOK.
 Fig. 24. *Modiola modiolus* LINN.
 Figs. 25 *a* and *b*. *Modiola* AFF. *japonica* DKR.
 Figs. 26 *a* and *b*. *Lima* AFF. *japonica* AD.
 Figs. 27 *a* and *b*. *Lima hakodatensis* TOK.

(All the figures excepting figs. 1 *a''* and *b*, figs. 2 *a* and *b*, fig. 8 *b*, fig. 9 *a'*, fig. 13 *b'*, figs. 14 *a* and *b*, fig. 15 *a'*, figs. 16 *a*, *a'* and *b*, fig. 17 *a'*, fig. 18, figs. 22 *a* and *b*, figs. 23 *a*, *b* and *c*, fig. 24, figs. 25 *a* and *b*, and figs. 26 *a* and *b* are in natural size).



S. TORUSAGA.

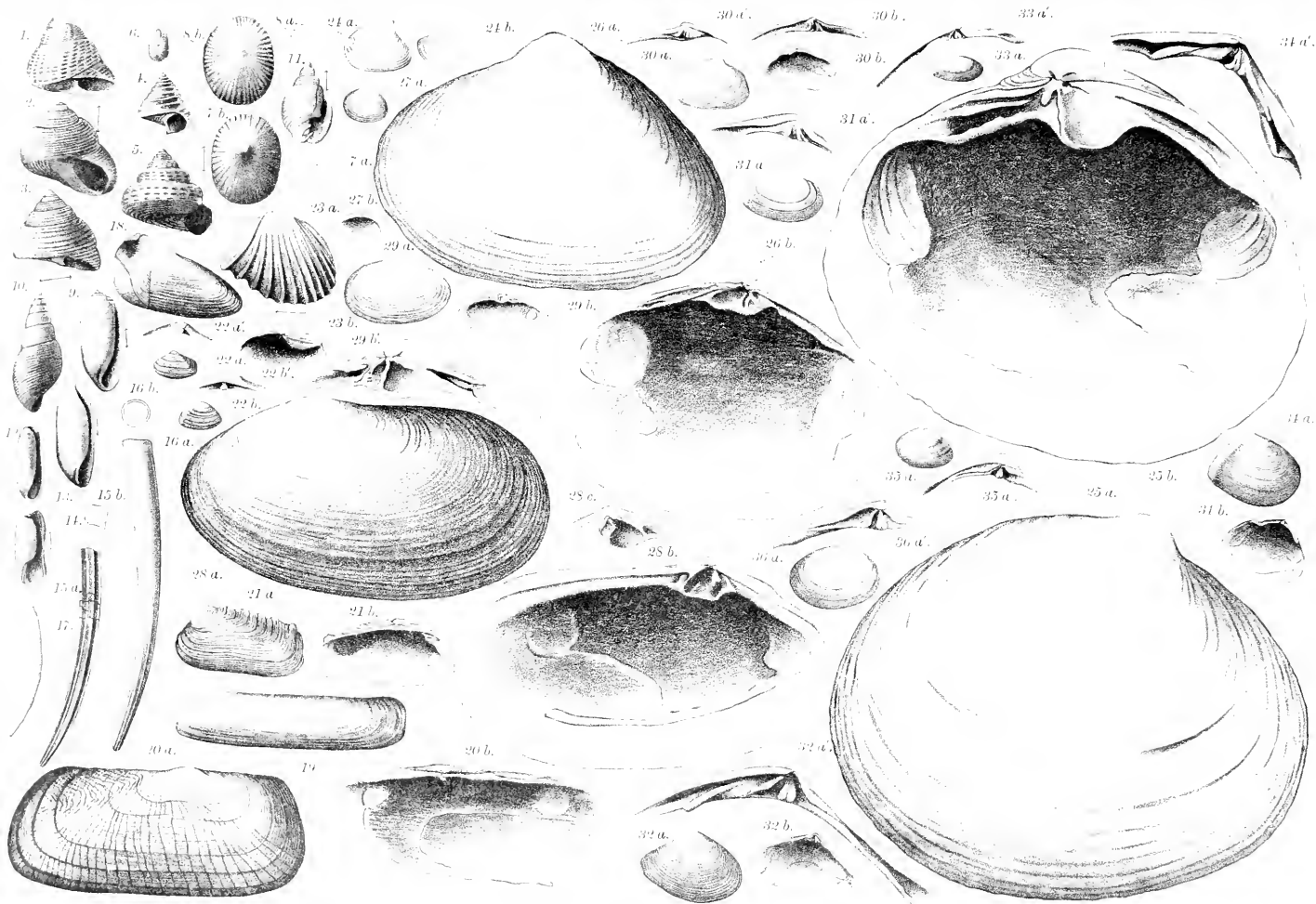
FOSSILS FROM THE ENVIRONS OF TOKYO.

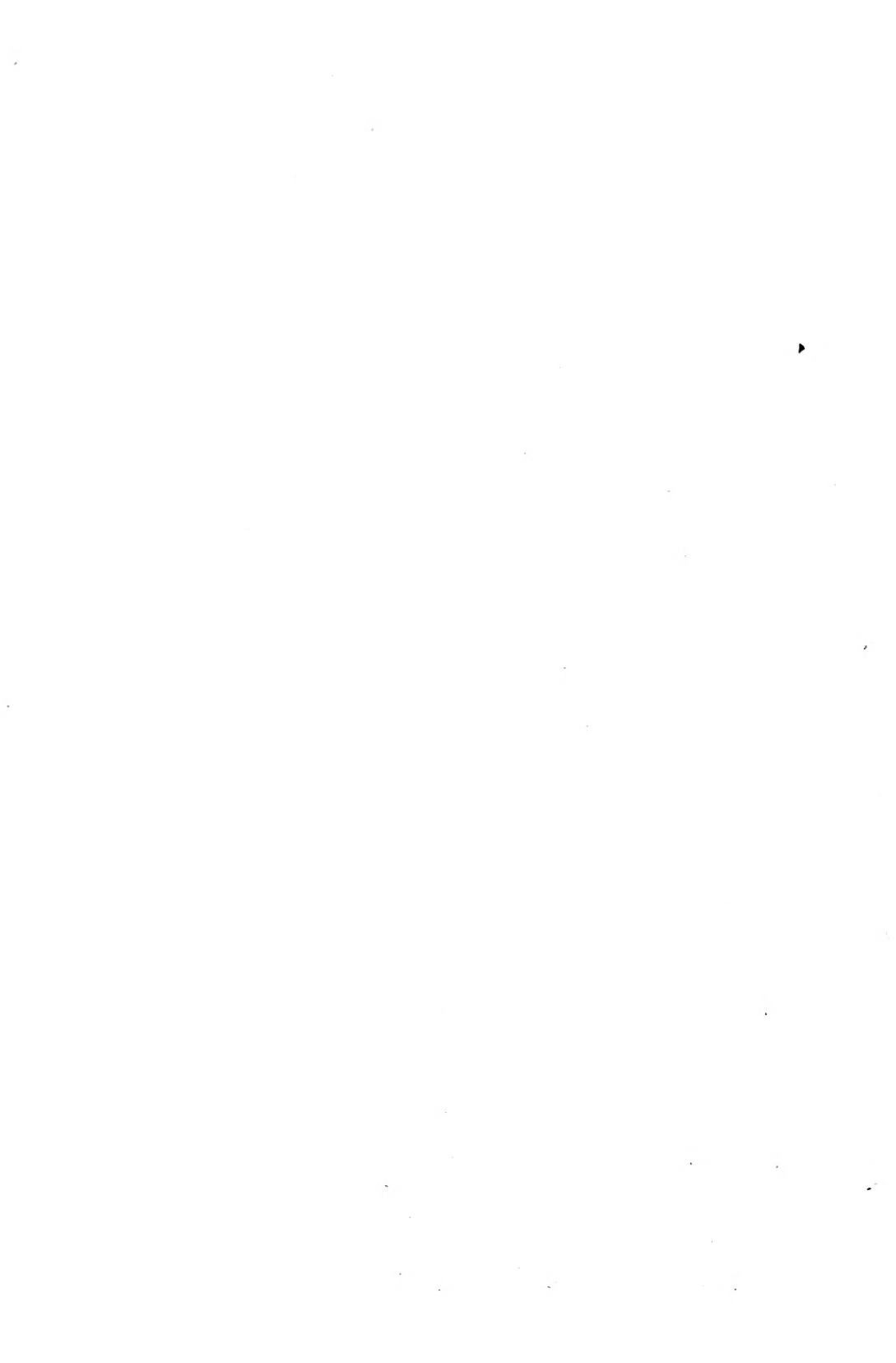
PLATE IV.

Plate IV.

- Figs. 1 *a* and *b*. *Arca tenuis* TOK.
Fig. 2. *Pecten lotus* GLD.
Fig. 3. *Pecten* AFF. *irradians* IAM.
Fig. 4. *Pecten pulchellimus* TOK.
Figs. 5 *a* and *b*. *Ostrea gigas* THUMB.
Figs. 6 *a* and *b*. *Ostrea denselamellosa* LIKE.
Figs. 7 *a* and *b*. *Ostrea irregularis* TOK.
Figs. 8 *a* and *b*. *Waldheimia grayi* DAY.
Figs. 9 *a* and *b*. *Waldheimia irregularis* TOK.
Fig. 10. *Lingula hians* SWAINS.

(All the figures excepting figs. 4, 9*a* and 9*b* are in natural size).





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PLATE V.

Plate V.

Figs. 1-10. *Pecten tokyoensis* Tok. (Nat. size).

Fig. 9.



Fig. 2.



Fig. 1.



Fig. 4.



Fig. 3.



Fig. 6.



Fig. 5.



Fig. 10.

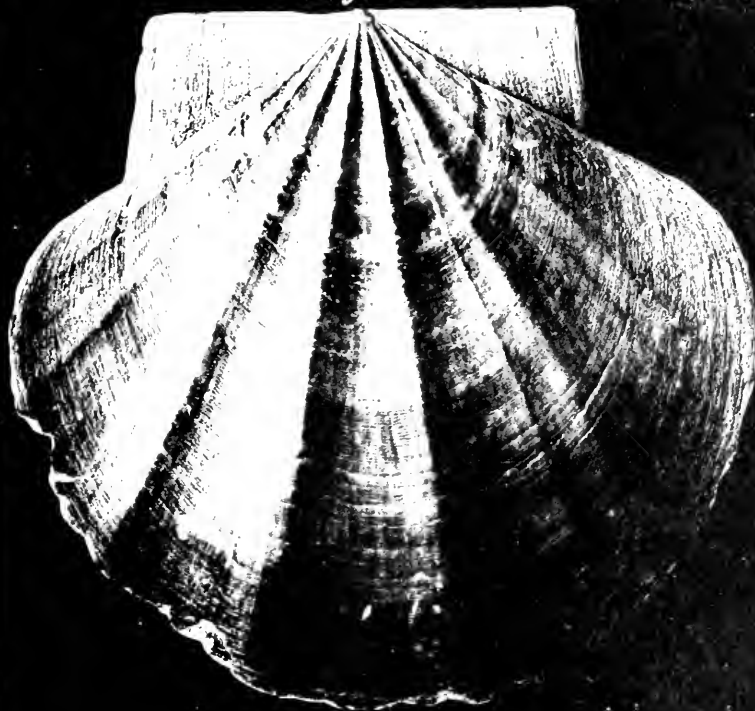
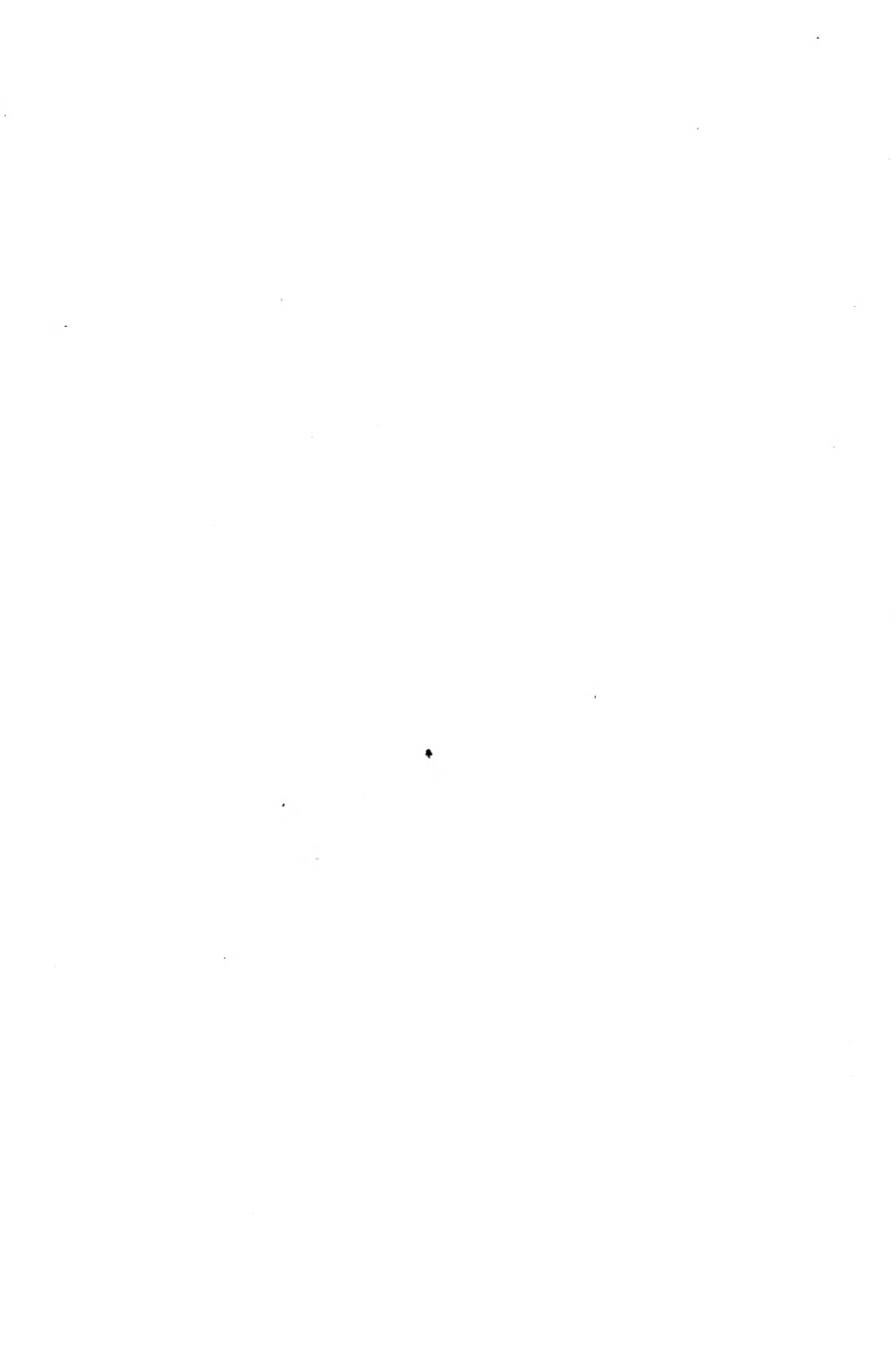


Fig. 7.



Fig. 8.





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PLATE VI.

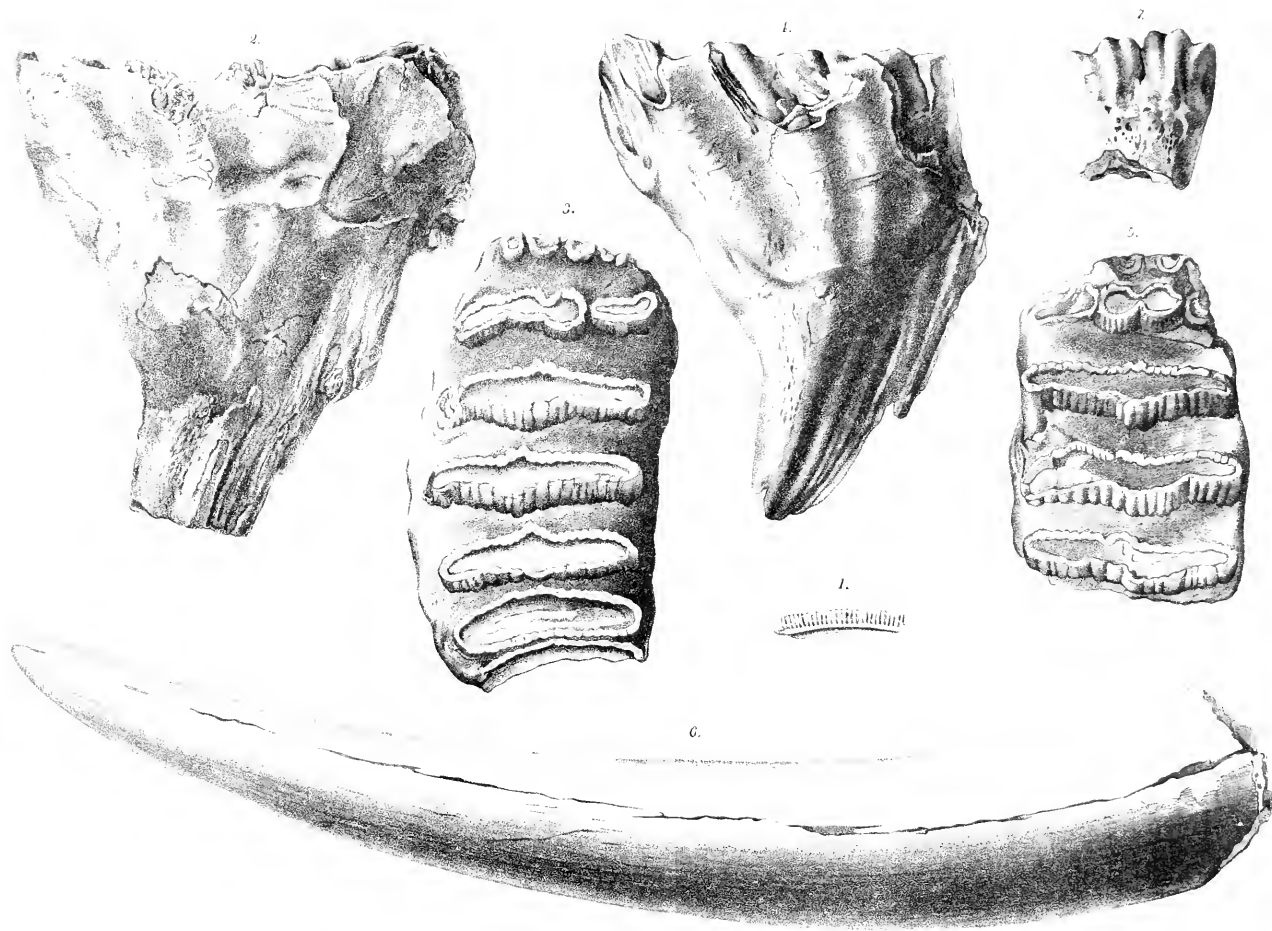
Plate VI.

Fig. 1. *Myliobatis* Sr.

Figs. 2-6. *Elephas antiquus* FALC.

Fig. 7. Indeterminable Ungulate bone.

(All figures in natural size).



Theory of the Rainbow due to a Circular Source of light.

By

K. Aichi *and* T. Tanakadate.

With 5 plates.

1. Introduction.

From the time of Descartes, many theories of the rainbow have been proposed, but Airy⁽¹⁾ was the first to establish a satisfactory theory on the undulatory theory of light. Airy's equation of the meridian section of the emergent wave-surface immediately after leaving the surface of the raindrop ($y=ax^3$), was, however, formed with reference to the tangent and normal to the curve at the point of inflexion, based on geometrical optics. This point in Airy's theory was afterwards developed in detail by Boitel,⁽²⁾ Larmor,⁽³⁾ and especially by Mascart⁽⁴⁾ and L. Lorenz.⁽⁵⁾ But all the above investigations were based on the assumption of a point source of light, and for the actual case

(1) Trans. Camb. Phil. Soc. VI. p. 379 (1838); VIII. p. 595 (1848).

(2) Compt. Rend. May 28, 1888; Phil. Mag. XXVI. p. 239 (1888).

(3) Proc. Camb. Phil. Soc. VI. p. 283 (1888).

(4) *Traité d'Optique*, I. p. 382 (1889); III. p. 430 (1893).

(5) *Œuvres Scientifiques*, I. p. 405 (Copenhagen, 1898).

of the rainbow which is due to a source of finite dimensions, the result holds only approximately. Recently, the colours of the rainbow have been minutely investigated by Pernter⁽¹⁾ with the use of Maxwell's theory of compound colours. In that paper Pernter also calculated the colours of the rainbow as due to a circular source of light, by a numerical addition of the results, due to seven point-sources in a straight line, each differing by $5'$. This method of calculation is not exact, and the result only holds as a rough approximation (see ante).

It is to be remarked that Pernter's values⁽²⁾ of Airy's integral $f^2(z)$, on which the whole calculation is based, are sometimes discrepant from those originally given by Airy. On comparing them with Airy's values, we found three mistakes at $z=1.8$, 2.2 and 3.6 , and Pernter himself, in his second paper,⁽³⁾ remarked that these mistakes came from Mascart's table and that they did not affect the final result of his calculation. For $z>8$, on drawing the curve representing Pernter's values, we found considerable irregularity. It seemed therefore advisable to repeat the calculation, using Stokes's semiconvergent series (see ante). The results of our calculations were always greater than Pernter's values, excepting the maxima and minima values. Some numerical examples are given in the following table:

z	f^2 : Pernter's	f^2 : our's
8.8	0.189	0.223
9.4	.100	.125
10.0	.240	.268
10.6	.022	.033
11.0	.170	.189

(1) Wien Sitz. Ber. CVI. 2a, p. 135 (1897); Neues über den Regenbogen (Wien, 1898).

(2) Loc. cit., p. 140.

(3) Wien. Sitz. Ber. CXIV. 2a, p. 1 (1905).

In our calculation we did not take the same numerical values for z that Pernter took. Thus in our values given above which were found by interpolation, there are probably small errors in the last figures.

So far as we are aware, the various calculations are as yet limited to cases which, strictly speaking, hold only for a point source of light. These considerations have led us to undertake the following investigation. It may therefore, be looked upon as an extension of Airy's theory to the case in which the source of light is circular, namely, when the apparent diameter of the sun is taken into account.

Next, let us consider the experimental side. Miller⁽¹⁾ and Pulfrich⁽²⁾ verified Airy's theory in the special case of two dimensions with a cylindrical stream of water (or glass rod), and a straight slit as the source of light. But a question suggests itself in connexion with the problem of the circular source of light—if we take account of the breadth of the slit, assuming its length to be infinite, what difference will occur? This question must be answered.

In the following, we shall start by briefly stating Airy's theory, and then proceeding to find differences when the source of light is replaced by a small circular disk; and after some additional notes on the two-dimensional case, the colours of the rainbow due to the sun are calculated in two cases, which may be taken as illustrations of the difference between the point and the circular source; and lastly experimental results will be discussed.

(1) Trans. Camb. Phil. Soc. VII. p. 277 (1841).

(2) Wied. Ann. XXXIII. p. 194 (1888).

2. Airy's theory.

It will be necessary, in the first place, to state Airy's theory in a form convenient for use in subsequent investigations. First, let us neglect the visual angle of the drop, i.e. the radius of the drop compared with the distance of the observer from the drop (in the case of table experiment, we have to consider the observer's distance as infinity, the telescope being so focussed). Describe a unit sphere having the centre c coinciding with that of the drop, and let the points o and s on the sphere be the directions of observer and point-source of light respectively, seen from c , and cm be the direction of the ray of minimum deviation in the plane sco . The position of the observer with respect to the sun is specified by the angle sco , or by the angle mco .

Put

$$\theta = \angle mco = D - \angle sco \quad (1)$$

where $D = \pi -$ angle of minimum deviation,

r = radius of the drop,

n = index of refraction,

$\rho - 1$ = number of internal reflections,

and
$$h = \frac{(\rho^2 - 1)^2}{\rho^2(n^2 - 1)} \sqrt{\frac{\rho^2 - n^2}{n^2 - 1}}.$$

Then the emergent wave-surface, being the surface of rotation with the axis sc , is specified by the curve of the intersection with the plane sco . Taking the coordinate origin at c , y -axis in cm and x -axis perpendicular to it, we have the equation of the curve

$$y = - \frac{h}{3n^2} x^3, \quad (2)$$

when we confine our attention to small values of θ ; and then the intensity of light in the direction ϕ is given by

$$i(\theta) = \text{const. } A f^2(x\theta) \quad (3)$$

where
$$A = \left(\frac{r^2}{h^2 \lambda} \right)^{\frac{1}{3}}, \quad (3_a)$$

$$x = 2 \left(\frac{6}{h} \right)^{\frac{1}{3}} \left(\frac{r}{\lambda} \right)^{\frac{2}{3}}, \quad (3_b)$$

$$f(x\theta) = \int_0^x \cos \frac{\pi}{2} (u^3 - x\theta u) du. \quad (3_c)$$

But, if we do not neglect the visual angle of the drop, the definition of θ must be slightly changed. In this case the ray of minimum deviation does not pass c , but meets the surface of the drop at a point say c' . Thus c' must be taken as the coordinate origin and $c'o'$ the direction of the observer; then θ is defined by

$$\theta = \angle c'o'm. \quad (1')$$

Using this value of θ , and neglecting $r\theta$ compared with the observer's distance, we may state the same formula as the above. For different wave lengths of light, the point c' is slightly displaced, but the amount of the displacement being negligibly small, we may take one position of c' as the coordinate origin for all the wave lengths of a visible ray.

Airy expanded $f(x\theta)$ as a power series of $x\theta$, which is not convenient for a practical calculation of values for $x\theta > 3$, though it always remains convergent. On the other hand, especially for large values of θ , the following semiconvergent series taken from Stokes⁽¹⁾ can be employed with advantage:—

$$f(x\theta) = 2^{\frac{1}{2}} 3^{-\frac{1}{4}} (x\theta)^{-\frac{1}{4}} M \cos \left(\mu - \frac{\pi}{4} - \alpha \right),$$

where
$$\mu = \pi \left(\frac{x\theta}{3} \right)^{\frac{3}{2}},$$

(1) Collected Papers, II. p. 329 (London, 1883).

$$M = 1 - 0.0347\mu^{-2}, \quad \tan \delta = 0.0694\mu^{-1};$$

or, approximately,

$$f(x\theta) = 2^{\frac{1}{2}} 3^{-\frac{1}{4}} (x\theta)^{-\frac{1}{4}} \cos \pi \left\{ \left(\frac{x\theta}{3} \right)^{\frac{3}{2}} - \frac{1}{4} \right\}$$

It must be remarked that both expansions only represent $f(x\theta)$ for $\theta > 0$. But for $\theta < 0$, $f(x\theta)$ being a function having no characteristic property, it is at once seen that no important difference appears between a point and a circular source. In the following discussion the places where $\theta < 0$ are therefore excluded.

3. Remarks on Airy's theory.

In his paper, Airy confined the value of θ within 2° , but he did not exactly determine the limit of approximation in his theory. Also he did not discuss the dependency of the intensity of the rainbow on the wave length of light. Pernter applied⁽¹⁾ Airy's theory for $\theta = 16^\circ$ not only to determine the positions of maxima and minima, but also to calculate the amount of intensity, and he said⁽²⁾ that θ might be 20° or 30° . Mascart took⁽³⁾ as the value of Λ of (β_a) at first

$$\Lambda = \left(\frac{r^2 \lambda^2}{\cos^2 \theta l^2} \right)^{\frac{1}{3}},$$

and then modified⁽⁴⁾ it to the form of (β_a) taking account of dimension.

We shall have to examine these points in detail, before proceeding to our discussion. First, in the equation (2), there was neglected the term of x^4 compared with x^3 . Differentiate (2) with respect of x and

(1) Wien, Sitz. Ber. CVI, 2a, Tab. I, 11 (1897).

(2) " " " CXIV, 2a, p. 6 (1905).

(3) Traité d'Optiques I, p. 391 (Copenhagen, 1889).

(4) " " " 111, p. 137 (" " 1893).

$$\frac{dy}{dx} = -\frac{h}{a^2} x^2 ,$$

put
$$\frac{dy}{dx} = \tan \varepsilon ,$$

then ε , being the angle between the tangent to the wave-front and the x -axis or the angle between the wave normal and the y -axis, is of the order of θ . It follows that x is of the order $\theta^{\frac{1}{2}}$. This shows that in (2) $\theta^{\frac{1}{2}}$ was neglected as compared with θ .

Secondly, the phase difference at a point x, y, z on the wave-surface is easily calculated from the equation (2), the z -axis being perpendicular to the x and y axes. Represent the position of the observer by ξ, η, ν , then the phase difference is

$$\delta = \sqrt{(x-\xi)^2 + (y-\eta)^2 + z^2} - \sqrt{\xi^2 + \eta^2} ,$$

or
$$\delta = \delta_1 + \delta_2 ,$$

where
$$\delta_1 = \frac{h}{3a^2} x^3 - \frac{\xi}{2\eta} x^2 , \quad \delta_2 = \frac{\eta^2}{2\eta} ,$$

x, z, ξ , being small compared with η . Then the intensity, being proportional to the square of the amplitude, is given by

$$i(\theta) = V_c^2 + V_s^2 ,$$

where
$$V_c = \frac{1}{k\eta} \int a \cos \frac{2\pi}{k} \delta \, d\sigma , \quad V_s = \frac{1}{k\eta} \int a \sin \frac{2\pi}{k} \delta \, d\sigma$$

$d\sigma$ being the surface element of the wave surface, and a the amplitude of the wave. In the case of a spherical drop, we have to put

$$a = cr \sin I ,$$

where I is the angle of incidence of the ray which has passed through $d\sigma$, and c depends on I, n, p , representing the effect of polarisation

or
$$a = cr \sin (I_0 + \gamma)$$

where I_0 is the angle of incidence of a ray of minimum deviation and $\gamma = I - I_0$. But in the position of minimum deviation

$$\frac{d\varepsilon}{d\gamma} = 0, \quad \frac{d^2\varepsilon}{d\gamma^2} = \text{finite},$$

i.e. ε is of the order γ^2 , or γ is of the order of $\theta^{\frac{1}{2}}$.

Thus, if we again neglect $\theta^{\frac{1}{2}}$ as compared with unity, i.e. $\theta^{\frac{3}{2}}$ compared with θ , we have

$$a = \text{const. } r$$

In the case of the circular cylinder, we have simply

$$a = \text{const.}$$

Thus, putting $d\sigma = dx dz$ and taking the limit of the integration from $-\infty$ to $+\infty$

$$V_c = \frac{\text{const.}}{\lambda\gamma} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial dx dz, \quad V_s = \frac{\text{const.}}{\lambda\gamma} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \sin \frac{2\pi}{\lambda} \partial dx dz$$

where

$$\begin{aligned} \cos \frac{2\pi}{\lambda} \partial &= \cos \frac{2\pi}{\lambda} (\partial_1 + \partial_2) \\ &= \cos \frac{2\pi}{\lambda} \partial_1 \cos \frac{2\pi}{\lambda} \partial_2 - \sin \frac{2\pi}{\lambda} \partial_1 \sin \frac{2\pi}{\lambda} \partial_2. \end{aligned}$$

Therefore

$$V_c = \frac{\text{const.}}{\lambda\gamma} \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial_1 dx \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial_2 dz.$$

In the first part of these integrals put

$$x = \left(\frac{6\lambda a^2}{h} \right)^{\frac{1}{3}} u, \quad 2 \left(\frac{6a^2}{\lambda^2 h} \right)^{\frac{1}{3}} = x,$$

$$\text{then} \quad \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial_1 dx = \left(\frac{6\lambda a^2}{h} \right)^{\frac{1}{3}} \int_0^{\infty} \cos \frac{\pi}{2} (u^3 - x\theta u) du,$$

$$\text{and in the second part} \quad z^2 = \frac{\lambda\gamma}{2} v^2$$

$$\text{then} \quad \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial_2 dz = \sqrt{\frac{\lambda\gamma}{2}} \int_{-\infty}^{+\infty} \cos \frac{\pi}{2} v^2 dv = \sqrt{\frac{\lambda\gamma}{2}}.$$

$$\text{Hence} \quad V_c = \frac{\text{const.}}{\sqrt{\lambda}} \left(\frac{\lambda a^2}{h} \right)^{\frac{1}{3}} \int_0^{\infty} \cos \frac{\pi}{2} (u^3 - x\theta u) du,$$

and similarly for V_s

$$V_s = -\frac{\text{const.}}{\lambda \eta} \int_{-\epsilon}^{+\epsilon} \cos \frac{2\pi}{\lambda} \partial_1 dz \int_{-\epsilon}^{+\epsilon} \sin \frac{2\pi}{\lambda} \partial_2 dz = V_c.$$

Thus, for a spherical drop

$$i(\theta) = \text{const.} \left(\frac{r^2}{\lambda h^2} \right)^{\frac{1}{3}} f^2(z\theta)$$

and for a circular cylinder

$$i(\theta) = \text{const.} \left(\frac{r^4}{\lambda h^2} \right)^{\frac{1}{3}} f^2(z\theta).$$

Of course, if we leave λ out of consideration, we may take as the expression for V_c and V_s

$$V_c = \text{const.} \int_{-\infty}^{+\infty} \cos \frac{2\pi}{\lambda} \partial_1 dz, \quad V_s = \text{const.} \int_{-\infty}^{+\infty} \sin \frac{2\pi}{\lambda} \partial_1 dz = 0,$$

as Airy, ∂_2 being small compared with ∂_1 .

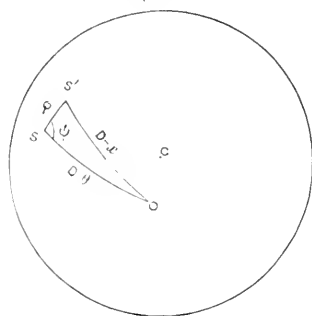
Airy's theory holds good only when $\theta^{\frac{1}{2}}$ is negligibly small, in other cases the theory must be essentially modified. If r is not negligible, then we have to take into account the dependency of the intensity of light on the angles of reflections and refractions, namely the effect of polarization as indicated by Mascart and Lorenz; on the other hand the form of the wave front must be modified by adding a term of x^4 . Thus some of Pernter's calculation for large values of θ can not be regarded as exact.

4. Extension of Airy's theory to that of a circular source.

Passing now to the case of a circular source of uniform intensity, the apparent diameter of the source 2Φ will be supposed so small that we can neglect Φ^2 compared with Φ , and confine our attention to the neighborhood of the minimum

deviation, so that Airy's theory applies. It is most convenient, in this case, to neglect the visual angle of the drop. Take the

Fig. 1.



elementary area of the projection s' of the source on the unit sphere, s being that of the centre of the circular source, and denote the angle between $s's$ and so by ϕ , the angular distance between s' and s by φ , the angle sco by $D-\theta$ and the angle $s'co$ by $D-x$. Then, in the spherical triangle $ss'o$,

we have the relation

$$\cos(D-x) = \cos\varphi \cos(D-\theta) + \sin\varphi \sin(D-\theta) \cos\phi,$$

which reduces to the form

$$x = \theta + \varphi \cos\phi,$$

since x , θ , φ are small.

The intensity of light at o due to the elementary area s' which is equal to $\varphi d\varphi d\phi$, is expressed by

$$\begin{aligned} \frac{1}{\varphi d\varphi d\phi}(\theta) &= \text{const. } \Lambda f^2(x, \varphi) \\ &= \text{const.} \left(\frac{r^2}{h^2 \lambda} \right)^{\frac{1}{3}} f^2 \left\{ x(\theta + \varphi \cos\phi) \right\} : \end{aligned}$$

from which it follows at once as the expression for the total intensity in the direction co , that

$$I(\theta, \Phi) = \text{const. } \Lambda F(z, \Phi, z\theta) \quad (4)$$

where
$$F(z, \Phi, z\theta) = \frac{1}{\pi \Phi^2} \int_0^\Phi \int_0^{2\pi} \varphi d\varphi d\phi f^2 \left\{ x(\theta + \varphi \cos\phi) \right\}, \quad (4_a)$$

$$\Lambda = \left(\frac{r^2}{h^2 \lambda} \right)^{\frac{1}{3}},$$

$$f^2 \{ x(\theta + \varphi \cos\phi) \} = \int_0^x \cos \frac{\pi}{2} \left\{ u^2 - x(\theta + \varphi \cos\phi) u \right\} du.$$

Thus the function f^2 in Airy's theory is replaced by a more general function F . From the form of the function f^2

and F , the difference between a point and a circular source is to be found. $f^2(z\theta)$ does not change for different values of z , if we reduce the scale of θ properly, because it is a function of $z\theta$, but not a function of z and θ taken separately; this however, does not hold for F , which is a function of z as well as of $z\theta$. Thus it is necessary to consider F more in detail, though its evaluation as a function of z , ϕ , and $z\theta$ is by no means easy.

If we try to expand $f^2\{z(\theta + \varphi \cos \phi)\}$ in a power series of $z\varphi \cos \phi$, then its coefficients gradually increase with $z\theta$, and are very inconvenient for values of $z\theta > 1$. If we change $f^2\{z(\theta + \varphi \cos \phi)\}$ to a double integral

$$\begin{aligned} & f^2\{z(\theta + \varphi \cos \phi)\} \\ &= \int_0^\pi \cos \frac{\pi}{2} - \left\{x^2 - z(\theta + \varphi \cos \phi)x\right\} dx \int_0^\pi \cos \frac{\pi}{2} - \left\{y^2 - z(\theta + \varphi \cos \phi)y\right\} dy \\ &= -\frac{1}{2} \int_0^\pi dx \int_0^\pi dy \left[\cos \frac{\pi}{2} - \left\{x^2 + y^2 - z\theta(x+y)\right\} \cos \frac{\pi}{2} - \left\{z\varphi \cos \phi(x+y)\right\} \right. \\ &\quad \left. - \sin \frac{\pi}{2} - \left\{x^2 + y^2 - z\theta(x+y)\right\} \sin \frac{\pi}{2} - \left\{z\varphi \cos \phi(x+y)\right\} \right. \\ &\quad \left. + \cos \frac{\pi}{2} - \left\{x^2 - y^2 - z\theta(x-y)\right\} \cos \frac{\pi}{2} - \left\{z\varphi \cos \phi(x-y)\right\} \right. \\ &\quad \left. - \sin \frac{\pi}{2} - \left\{x^2 - y^2 - z\theta(x-y)\right\} \sin \frac{\pi}{2} - \left\{z\varphi \cos \phi(x-y)\right\} \right] , \end{aligned}$$

and integrate with respect to φ and ϕ , by using the relations of Bessel's function

$$J_0(w) = \int_0^\pi \cos(w \cos \mu) d\mu ,$$

$$0 = \int_0^\pi \sin(w \cos \mu) d\mu ,$$

and

$$\frac{d}{dw} \left\{ w^{\frac{1}{2}} J_1(w) \right\} = \frac{1}{2} J_0(w) ,$$

then the final form is

$$\int_0^x \int_0^x dx dy \left[\cos \frac{\pi}{2} \left\{ x^3 + y^3 - z\theta(x+y) \right\} \frac{J_1 \left\{ \frac{\pi}{2} z\Phi(x+y) \right\}}{\frac{\pi}{2} z\Phi(x+y)} \right. \\ \left. + \cos \frac{\pi}{2} \left\{ x^3 - y^3 - z\theta(x-y) \right\} \frac{J_1 \left\{ \frac{\pi}{2} z\Phi(x-y) \right\}}{\frac{\pi}{2} z\Phi(x-y)} \right] .$$

Putting $x = x' \left(\frac{2}{\pi} \right)^{\frac{1}{3}} \quad y = y' \left(\frac{2}{\pi} \right)^{\frac{1}{3}} \quad z = z' \left(\frac{2}{\pi} \right)^{\frac{2}{3}}$

and $y' = -y'$ in the latter half,

then applying the well-known sequence equation of the Bessel's function

$$-\frac{J_1(w)}{w} = \frac{1}{2} \left\{ J_2(w) + J_0(w) \right\} ,$$

this can be reduced to the form

$$\int_0^x \int_{-x}^{+x} dx' dy' \cos \left\{ x'^3 + y'^3 - z'\theta(x' + y') \right\} \left[J_2 \left\{ z'(x' + y') \right\} + J_0 \left\{ z'(x' + y') \right\} \right] ,$$

which is almost intractable for practical calculation.

If we transform the variables φ, ψ to x, y which are given by $x = \varphi \cos \psi, y = \varphi \sin \psi$, and then integrate with respect to y , we arrive at the expression

$$F(z, \Phi, z\theta) = \frac{2}{\pi \Phi^2 z^2} \int_{-z\Phi}^{+z\Phi} d(z\psi) \sqrt{(z\varphi)^2 - (z\psi)^2} J^2(z\theta + z\psi) . \quad (4')$$

This form is most advantageous for the numerical calculation of F by means of mechanical quadrature.

5. Case where the visual angle of the drop is not negligible.

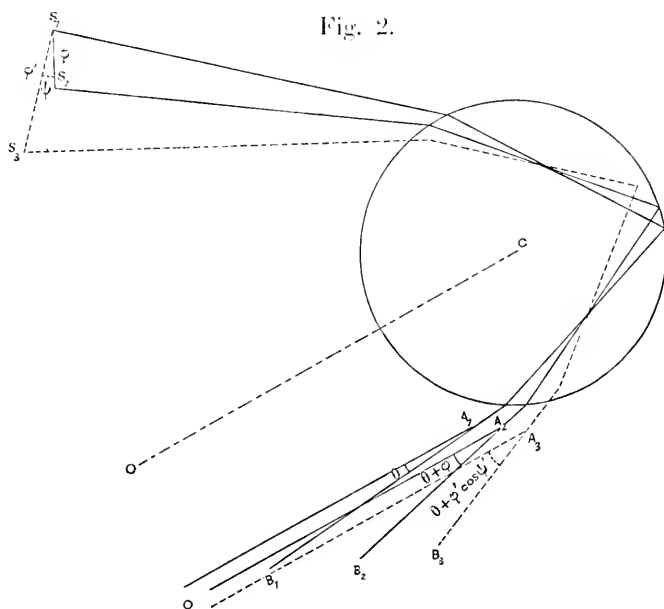
In the preceding article we neglected the visual angle of the drop, i.e. r as compared with the observers distance, but

when this is not the case, the consideration is more complicated. Firstly, let us consider the case where the source of light consists of three points s_1, s_2, s_3 lying in a plane perpendicular to s_1c at a great distance. In the plane s_1co , the intensity of the rainbow due to s_1 , is

$$i_{s_1}(\theta) = c_1 \Lambda_1 f^2(z\theta)$$

where θ represents the angle $B_1 \Lambda_1 O$, $B_1 \Lambda_1$ being the direction of the minimum deviation due to s_1 . Suppose that s_2 lies in the plane s_1co , and its angular distance φ from s_1 , is small; then the intensity due to s_2 in the direction $\Lambda_1 O$ or $\Lambda_2 O$ is

$$i_{s_2}(\theta) = c_2 \Lambda f^2\{z(\theta + \varphi)\}.$$



Next suppose that s_3 lies in another plane s_3co , and its position is represented by φ' and ψ , where φ' is the small angular distance of s_3 from s_1 and ψ the angle subtended by $s_1 s_2$ and $s_1 s_3$. Now then, in the plane s_3co there is no direction parallel to

A_1O , but there exists a direction which makes the angle θ with A_1B_1 , and the intensity in this direction is given by

$$i_{s_3}(\theta) = c_3 A_1 f^2 \left\{ z(\theta + \varphi' \cos \phi) \right\} .$$

Thus, in the plane s_1co we have as the total intensity

$$i(\theta) = i_{s_1}(\theta) + i_{s_2}(\theta) ,$$

and in the plane s_3co

$$i'(\theta) = i_{s_3}(\theta) .$$

In this case, therefore though $i(\theta)$ and $i'(\theta)$ do not exist in one direction nor in one plane, they exist in the same arc of the rainbow which is specified by θ . Hence, the distribution of the intensity of the rainbow can not be considered as uniform along the arc of the rainbow.

The above method is directly applicable to the case of a circular source of light. To determine the position of a point in the source of light, take the centre s_0 of the source as the origin from which φ is measured, the diameter D_0 of the source which lies in the plane s_0co as the axis from which ϕ is measured, and the direction of the minimum deviation due to s_0 as the y -axis from which θ is measured. Then, in the plane s_0co , the intensity of the rainbow is given by

$$I(\theta) = \text{const. } A \int_{-\Phi}^{+\Phi} f^2 \left\{ z(\theta + \varphi) \right\} d\varphi , \quad (a)$$

Φ being the angular radius of the circle. Pernter took this integral as the general expression of the intensity of the rainbow due to a circular source of light and condemned our result, but this holds only in the plane s_0co . Let us consider another plane which cuts the source in another line L and contains c and o .

Then, the line L does not pass the centre of the source, but is approximately parallel to D_0 . Representing the angular distance of L from D_0 by y , and the angular length measured from the middle point of L along L by x , we have as the intensity due to L in the direction θ in the plane Lco ,

$$I(\theta) = \text{const.} \cdot \Lambda \int_{-1}^{+1} \frac{\sqrt{\Phi^2 - y^2}}{\sqrt{\Phi^2 - y^2}} f^2 \{z(\theta + x)\} dx. \quad (b)$$

This value of $I(\theta)$ being a function of y , holds for any plane which contains a part of the source and c, o . For a particular value $y=0$, (b) reduces to (a), and when $y=\Phi$, $I(\theta)$ becomes zero.

The above discussion shows that, in general, when both the angular diameters of the source and of the drop are not negligible, the intensity of the rainbow can not be considered as uniform along the arc of the rainbow; and exact investigation is almost impossible unless we are informed of the distribution of the drops. Again, if we consider the drop so large that the distance of the lines A_1O, A_2O in Fig. (2) is greater than the pupil of the observer's eye, the result must be considerably changed.

If we take the mean value of intensity $I(\theta)$ along the arc of the rainbow which is specified by θ as

$$I_m(\theta) = \text{const.} \cdot \Lambda \int_0^\Phi \int_{-1/\sqrt{\Phi^2 - y^2}}^{+1/\sqrt{\Phi^2 - y^2}} f^2 \{z(\theta + x)\} dy dx,$$

changing the order of integration, we have

$$I_m(\theta) = \text{const.} \cdot \Lambda \int_0^\Phi dx \sqrt{\Phi^2 - x^2} f^2 \{z(\theta + x)\}$$

or

$$I_m(\theta) = \text{const.} \cdot \Lambda \int_{-z\Phi}^{+z\Phi} d(zx) f^2 \left\{ z(\theta + x) \right\} \sqrt{(z\Phi)^2 - (zx)^2}.$$

This coincides with (4'), i.e. the result when we neglect the angular diameter of the drop.

6. General nature of the intensity curve.

It will be advantageous to consider first the maxima and minima of F as compared with those of f^2 , and then to discuss the general character, and finally proceed to the numerical calculation of F . In the expression (4') in § 4 put $xz=z$, then

$$F(z, \Phi, z\theta) = \frac{2}{\pi\Phi^2 z^2} \int_{-z\Phi}^{+z\Phi} dz \sqrt{(z\varphi)^2 - z^2} f^2(z\theta + z).$$

Thus the maxima and minima of F are given by

$$\int_{-z\Phi}^{+z\Phi} dz \sqrt{(z\varphi)^2 - z^2} \frac{\partial}{\partial \theta} \left\{ f^2(z\theta + z) \right\} = 0;$$

$$\int_{-z\Phi}^{+z\Phi} dz \sqrt{(z\varphi)^2 - z^2} \frac{\partial}{\partial z} \left\{ f^2(z\theta + z) \right\} = 0.$$

Or, putting the mean value of $\sqrt{(z\varphi)^2 - z^2}$ in the integral, we arrive at the approximate relation

$$f^2(z\theta - z\Phi) = f^2(z\theta + z\Phi).$$

For smaller values of θ , especially at the first maximum, f^2 has no symmetry on both sides of the maxima and minima (see Pl. I.); so that the first maximum of F receives a small displacement towards $\theta=0$ as compared with f^2 . This displacement becomes smaller and smaller for other maxima and minima. For larger values of θ , as f^2 is nearly symmetrical on both sides, the maxima and minima approximately coincide with those of

f^2 ; nevertheless it does not follow that the maxima for f^2 always remain as maxima for F .

For the consideration of the general character of F , we shall begin with that of f^2 . By Stokes's expression

$$f^2(z\theta) = \frac{2}{1-3} \frac{1}{1-z\theta} \cos^2 \pi \left\{ \left(\frac{z\theta}{3} \right)^{\frac{3}{2}} - \frac{1}{4} \right\} = \frac{1}{1-3\sqrt[3]{z\theta}} - \frac{\sin 2\pi \left(\frac{z\theta}{3} \right)^{\frac{3}{2}}}{1-3\sqrt[3]{z\theta}}.$$

f^2 is composed of two terms: the mean term $\frac{1}{1-3\sqrt[3]{z\theta}}$, and the oscillating term, whose amplitude is limited by the same numerical factor $\frac{1}{1-3\sqrt[3]{z\theta}}$; therefore at maxima f^2 increases to $2 \times$ (mean term) and at minima decreases to zero. But the character of F is slightly different, since

$$F(z, \Phi, z\theta) = \frac{2}{\pi \Phi^2 z^2} \int_{-z\Phi}^{+z\Phi} dz \sqrt{(z\zeta)^2 - z^2} \left[\frac{1}{1-3\sqrt[3]{z\theta+z}} - \frac{\sin 2\pi \left(\frac{z\theta+z}{3} \right)^{\frac{3}{2}}}{1-3\sqrt[3]{z\theta+z}} \right].$$

The first term is equal to

$$\frac{2}{\pi \Phi^2 z^2} \int_{-z\Phi}^{+z\Phi} dz \sqrt{(z\zeta)^2 - z^2} \frac{1}{1-3\sqrt[3]{z\theta}} \left(1 - \frac{z}{2z\theta} + \dots \right),$$

and leads to the same mean term so far as the first order of $\frac{z}{z\theta}$ is concerned. But the second term, after putting $\frac{\pi z\Phi}{4} \frac{1}{z\theta}$ as the mean value of $\frac{1}{z\theta+z}$, and integrating with respect to a new variable $2\pi \left(\frac{z\theta+z}{3} \right)^{\frac{3}{2}}$, becomes

$$\frac{\cos 2\pi \left(\frac{z\theta - z\Phi}{3} \right)^{\frac{3}{2}} - \cos 2\pi \left(\frac{z\theta + z\Phi}{3} \right)^{\frac{3}{2}}}{6\pi z\Phi z\theta} = \frac{\sin 2\pi \left(\frac{z\theta}{3} \right)^{\frac{3}{2}} \sin \left(\frac{1}{3} \pi z\Phi \sqrt[3]{z\theta} \right)}{3\pi z\Phi z\theta}.$$

Thus the amplitude of the oscillating term is limited by $\frac{\sin \left(\frac{1}{3} \pi z\Phi \sqrt[3]{z\theta} \right)}{3\pi z\Phi z\theta}$ which is much smaller than $\frac{1}{1-3\sqrt[3]{z\theta}}$; and, moreover, this may be positive or negative according to the sign of $\sin \left(\frac{1}{3} \pi z\Phi \sqrt[3]{z\theta} \right)$. For the smaller value of Φ , $\frac{1}{3\pi z\Phi z\theta}$ becomes

larger and the period of $\sin(\frac{1}{\sqrt{3}}\pi z\Phi_1/\sqrt{z}\theta)$ is prolonged; in the limiting case $\Phi=0$, $\frac{\sin(\frac{1}{\sqrt{3}}\pi z\Phi_1/\sqrt{z}\theta)}{3\pi z\Phi_1\theta}$ becomes equal to $\frac{1}{\frac{1}{\sqrt{3}}\frac{1}{\sqrt{z}\theta}}$, as expected. Also for smaller values of z , i.e. of r , the same reasoning will hold true. Thus for large values of Φ and r , the difference of the two cases becomes manifest.

From this approximate expression,

$$F = \frac{1}{\frac{1}{\sqrt{3}}\frac{1}{\sqrt{z}\theta}} - \frac{\sin 2\pi\left(\frac{z\theta}{3}\right)^{\frac{3}{2}} \sin(\frac{1}{\sqrt{3}}\pi z\Phi_1/\sqrt{z}\theta)}{3\pi z\Phi_1\theta}$$

it follows that F does not increase at maxima to $2\times$ (mean term), but only to $\left(\text{mean term} + \frac{1}{3\pi z\Phi_1\theta}\right)$; and at minima it does not diminish to zero, but only to $\left(\text{mean term} - \frac{1}{3\pi z\Phi_1\theta}\right)$; moreover, for values of θ for which $\sin(\frac{1}{\sqrt{3}}\pi z\Phi_1/\sqrt{z}\theta) < 0$, the maxima of $\sin 2\pi\left(\frac{z\theta}{3}\right)^{\frac{3}{2}}$ changes to minima and the minima to maxima. Finally, the expression for the intensity being

$$i(\theta) = \text{const.} \left(\frac{r^2}{h^2\lambda}\right)^{\frac{1}{3}} I^2(z\theta) \quad \text{for point source,}$$

$$I(\theta, \Phi) = \text{const.} \left(\frac{r^2}{h^2\lambda}\right)^{\frac{1}{3}} F(z, \Phi, z\theta) \quad \text{for circular source;}$$

it follows, first, that for larger values of Φ , the difference of $i(\theta)$ and $I(\theta, \Phi)$ becomes larger; secondly, that for larger values of r , the difference of maximum and minimum values of $i(\theta)$ becomes larger in virtue of $r^{\frac{2}{3}}$, but for $I(\theta, \Phi)$ at the same time it is diminished by the presence of F .

7. Case of the cylinder and slit.

We shall now treat the case which has often been tested by experiment with the glass rod, and straight slit as the source of light. In this case, if we neglect the breadth of the slit,

Airy's theory applies as well as in the case of the spherical drop, when we change the value of Λ

$$i(\theta) = \text{const. } \Lambda' f^2(z\theta)$$

where
$$\Lambda' = \left(\frac{r^4}{h^2 \lambda} \right)^{\frac{1}{3}}.$$

If we take into account the breadth of the slit, there is no difficulty in applying reasoning similar to the above, to arrive at the expression

$$I(\theta, \Phi) = \text{const.} \left(\frac{r^4}{h^2 \lambda} \right)^{\frac{1}{3}} F_1(z, \Phi, z\theta)$$

$$F_1(z, \Phi, z\theta) = \int_{-z\Phi}^{+z\Phi} f^2(z\theta + z)\rho z$$

where 2Φ = the angular breadth of the slit as viewed from the centre of the glass rod. Or putting $z = z\varphi$,

$$F_1(z, \Phi, z\theta) = \int_{-\Phi}^{+\Phi} f^2\{z(\theta + \varphi)\} d\varphi.$$

This coincides with the integral at (a) on which Pernter's calculation was based. Hence, we see that Pernter's integral holds good for the case of slit and cylinder, but not for the case of circle and sphere.

The difference of the expression of Λ in the two cases of sphere and cylinder was not discussed by Airy and others; but the existence of the difference is evident from the geometrical theory of the rainbow, in which the intensity is proportional to r^2 in the case of the sphere and to r in the case of the cylinder.

In § 6 we always substituted the mean value of $\sqrt{1 - (z\varphi)^2 - z^2}$ before integration, so that the expression for F becomes only roughly approximate; but in the present case, there being no

such term as $\sqrt{(z\varphi)^2 - z^2}$, this expression for F must be taken as nearly true.

Thus the maxima and minima of F_1 are given by

$$f^2(z\theta + z\psi) - f^2(z\theta - z\psi) = 0,$$

and to determine whether they correspond to maxima or minima, we have to consider the sign of

$$-\frac{\partial}{\partial \theta} \left\{ f^2(z\theta + z\psi) - f^2(z\theta - z\psi) \right\}.$$

This being given by the directions of the tangents to the curve of f^2 (Pl. I) at the points $z\theta + z\psi$, and $z\theta - z\psi$, we see at once that when the intervals of the consecutive maxima or minima are greater than $z\psi$, maxima of f^2 correspond to maxima of F , but when $z\psi$ exceeds the intervals of the consecutive maxima or minima, the maxima of f^2 correspond to minima of F .

The maxima and minima not only interchange places at certain points, but the interval between the maxima and minima slightly increases, as a consequence that the first maximum being displaced towards $\theta=0$, while the higher maxima, showing the same tendency, are displaced by smaller amounts. In Pulfrich's experiment, where he takes the third maximum as standard, the first and second are displaced slightly toward $\theta=0$, and the other to the opposite side, as compared with Airy's values of f^2 . This displacement may be partly due to the breadth of the slit.

3. Numerical calculation.

For numerical calculation we must have recourse to mechanical quadrature. The method of procedure is as follows:— Draw a circle having the centre at $z\theta$ and radius equal to $z\psi$,

then plot a curve whose ordinate is equal to the product of the value of f^2 into the corresponding ordinate of this circle; the area of the new curve divided by the area of this circle is the value of F at $z\theta$. The following table has been made according to this method.

2Φ =apparent diameter of the sun=32'

$z\theta$: (except 0) max. and mini. of Airy's value.

In Table I

F_1 : $r=0.025$ cm.	$\lambda=5893 \times 10^{-8}$ cm.	$z=120.95$
F_2 : $r=0.05$ cm.	$\lambda=5893 \times 10^{-8}$ cm.	$z=192.00$

TABLE I.

$z\theta$	f^2	F_1	F_2
0	0.443	0.447	0.465
1.084	1.008	0.930	0.840
2.495	0.000	0.103	0.228
3.467	0.617	0.497	0.362
4.363	0.000	0.124	0.237
5.145	0.510	0.378	0.260
5.892	0.000	0.133	0.235
6.578	0.450	0.300	0.206
7.244	0.000	0.140	0.223
7.868	0.404	0.254	0.177
8.479	0.384	0.230	0.164
9.060	0.000	0.148	0.199
10.177	0.362	0.207	0.155
10.716	0.000	0.150	0.195

The graphical representation of this table is given at the end of the paper, where f^2 is represented by the dotted, F_1 by broken and F_2 by solid lines (Pl. I).

In Table II

$F_s :$	$r=0.025$ cm.	$\lambda=6302 \times 10^{-8}$ cm.
$F_g :$	„	$\lambda=5211 \times 10^{-8}$ cm.
$F_b :$	„	$\lambda=4659 \times 10^{-8}$ cm.

TABLE II.

$z\theta$	F_s	F_g	F_b
0	0.149	0.456	0.456
1.084	938	927	912
2.495	097	121	139
3.467	492	473	451
4.363	119	148	166
5.145	380	351	333
5.892	126	150	173
6.578	306	281	265
7.244	133	154	175
7.868	250	230	216
8.499	135	155	174
9.060	232	207	196
9.630	137	159	176
10.177	209	190	176
10.716	138	162	177

In Table III

$F_s :$	$r=0.05$ cm.	$\lambda=6302 \times 10^{-8}$ cm.
$F_g :$	„	$\lambda=5211 \times 10^{-8}$ cm.
$F_b :$	„	$\lambda=4659 \times 10^{-8}$ cm.

TABLE III.

$z\theta$	F_s	F_g	F_b
0	0.482	0.484	0.484
1.084	869	837	814
2.495	215	262	290

TABLE III. (*Continued*).

$z\theta$	f_s	F_g	F_b
3.467	0.394	0.353	0.326
4.363	231	267	293
5.145	263	237	230
5.892	222	253	262
6.578	216	199	189
7.244	223	237	237
7.868	166	169	181
8.479	208	209	204
9.060	166	165	162
9.630	202	204	204
10.177	165	155	156
10.716	187	196	197

In the case of slit and cylinder, the method of mechanical quadrature is simpler; the mean value of f^2 in the interval $z\theta - z\phi$ and $z\theta + z\phi$ representing the value of F_1 at $z\theta$. Pernter's method of calculation which we have described in § 1 is applicable in this case only. He calculated the case where $r=0.025$ cm., and compared⁽¹⁾ with our result, shows that there was no great difference in both results. This fact shows that there is no great difference in the two cases, of slit-cylinder and of circle-sphere. Thus, fortunately, Pernter's method of calculation applies as a rough approximation for the case of circle-sphere, though his reasoning was not exact. It seems rather curious that in his calculation for $r=0.05$ cm., we can not find the general nature in § 7; when the interval of consecutive maxima or minima of F is less than $z\phi$, the maxima and minima interchange.

(1) Wien Sitz. Ber. CXIV. 2a, p. 13 (1905).

9. Colours of the rainbow.

Pernter calculated the colours of the rainbow due to the sun, but his calculation was not sufficient to establish the above-mentioned results. We repeated the calculation for two cases. The theory of compound colours being the subject of much dispute, there is as yet no settled opinion. But we can admit that, excluding the physiological and psychological points of view, there are three primary colours, as Maxwell's experiment⁽¹⁾ shows. For the discussion of the colours of the rainbow, we may conveniently take only these three primary colours, in such a ratio as to produce white, and proceed in the manner indicated by Maxwell.

We take the primary colours

$$\begin{array}{lll} \lambda = 6302 \times 10^{-8} \text{ cm.} & 5211 \times 10^{-8} \text{ cm.} & 4659 \times 10^{-8} \text{ cm.} \\ \text{(Scarlet)} & \text{(Green)} & \text{(Blue)} \end{array}$$

corresponding to Maxwell's

$$\begin{array}{lll} [24] & [46] & [64] \end{array}$$

in the ratio 1 : 1.62 : 1.60, so as to produce white,

$$\text{and} \quad n = 1.332 \quad 1.335 \quad 1.339$$

$$\text{whence} \quad D = 42^{\circ}22' \quad 41^{\circ}80' \quad 41^{\circ}21'$$

and for $r = 0.025 \text{ cm.}$

$$z = 115.3 \quad 131.6 \quad 142.9$$

for $r = 0.05 \text{ cm.}$

$$z = 183.0 \quad 209.0 \quad 226.9$$

Thus we obtain the values of F given by Table II and Table III in the preceding article. The results of compound colours represented by Pl. II.....Pl. V, Pl. II and Pl. IV

(1) Scientific Papers, I. p. 410 (Cambridge, 1893).

corresponding to the case of the point source, and Pl. III and Pl. V to the circular source ($2\Phi=32'$ mean angular diameter of the sun), r in Pl. II and Pl. III being 0.025 cm., and in Pl. IV, Pl. V 0.05 cm. The intensity of the scarlet ray is given by dotted; green by broken; blue by solid lines, and the sum of the three intensities, i.e. the total intensity, by curve (1), which is compounded of a portion of white and a portion of the two primary colours.

For example, in Pl. II:—

I at $41^\circ 5'$	consists of	27 percent.	scarlet,	48 percent.	green,	25 percent.	white,
$40^\circ 5'$	„	14	„	blue,	14	„	scarlet, 72 „ white,
38°	„	23	„	green,	77	„	blue, 0 „ white.

In Pl. III:—

I at $41^\circ 5'$	consists of	24 percent.	scarlet,	43 percent.	green,	33 percent.	white,
$40^\circ 5'$	„	21	„	blue,	9	„	scarlet, 70 „ white,
38°	„	9	„	green,	19	„	blue, 72 „ white.

where the angles correspond to $s_0co=D-\theta$ in § 4.

The above calculation shows that in the colours of the supernumerary bows due to the sun, white predominates, and we can not distinguish many numbers of the supernumerary bows. This explains the fact *that the rainbow in nature is accompanied by only a small number of supernumerary bows, while according to Airy's theory the rainbow ought to be accompanied by numerous bows.*

According to § 6, we notice that the difference between the maximum and minimum values of intensity increases with the size of the drop for a point source; but for a circular source the intensity depends on two factors, one of which enjoys the same property as for a point source, but the other produces a

contrary effect. Montigny⁽¹⁾ says that supernumerary bows are numerous when the drops are small. This holds for the case of a circular source and supports our view, but he considers this as the result of Airy's theory, i.e. of a point source, which we cannot understand.

10. Summary.

From the above discussion, we obtain the following result, where (1) represents the case of a point source, (2) a circular source :—

(a) The positions of the maxima and minima of (2) approximately coincide with those of (1). Strictly speaking, the first maximum of (2) is displaced by a small amount towards $\theta=0$ as compared with (1), and for other maxima and minima this displacement becomes smaller and smaller. But the maxima of (2) may correspond to the minima of (1), and the minima to the maxima.

(b) The value of (2), which corresponds to the maximum of (1), is smaller than that of (1), and the value of (2), which corresponds to the minimum of (1) is greater than that of (1). This difference between (1) and (2) increases with the value of Φ (i.e. with the increased diameter of the source).

(c) As the value of θ increases, the maximum value of (1) and (2) gradually decreases. While the minimum value of (1) always remains 0, the minimum value of (2) gradually increases until it becomes equal to the maximum value and assumes a stationary value, then the maxima and minima interchange, the difference of the maximum and minimum values at first increases and then decreases, then again assumes a stationary value, and

(1) Phil. Mag. IX. p. 339 (1880).

so on. If in this interval between the two stationary values the maxima of (2) correspond to those of (1), then in the next interval the maxima of (2) correspond to the minima of (1).

(d) For larger values of r (radius of the drop) the intensity of (1) and (2) increases by $r^{\frac{5}{3}}$. But at the same time for (2), the difference between the maximum and minimum values is diminished by another factor F .

(e) The above is more manifestly shown in the case of the laboratory experiment with a cylindrical glass rod and a straight slit as the source of light. The stationary points of (2) at which the maximum value coincides with the minimum are easily found by

$x\Phi = m \times$ interval of the maximum and minimum of (1),
where m represents an integer.

(f) According to Airy's theory, the law of the distribution of the colours of the rainbow is independent of the magnitude of the drop. But in the case of the finite source, the colour distributions are changed by the magnitude of the drop, especially in the supernumerary bows.

(g) The supernumerary bows almost lose their colour as the consequence of the finiteness of the source. This effect is more remarkable when the drop becomes larger.

11. Note on the experimental side.

To show the above-mentioned results, we repeated rough experiments with glass rods and a straight slit as the source of light.

Using homogeneous light, we see that when the slit is very narrow the phenomena nearly coincide with Airy's theory, and

that when the breadth of the slit is increased, the positions of the bows (or fringes in this case) change very little. As another effect of the increase of the breadth of the slit, the bows become indistinct, especially the supernumerary bows. This effect is remarkable when the diameter of the rod is large. We could not observe the turning point, at which the maxima and minima interchange, as the difference of the intensities is very small. But we can roughly say that the point at which the bows become almost indistinguishable corresponds to the position at which the angular breadth of the bow coincides with that of the slit.

Again, using white light, it is easy to see that the colours of the supernumerary bows change when the magnitude of the rod is changed, and that the supernumerary bows almost lose colour and become indistinct when the breadth of the slit is increased.

In the table experiment, we always observed that, when the breadth of the slit is not too large, the supernumerary bows are numerous for a cylinder with a large radius, but fewer for a small cylinder. This fact may be explained by the presence of the factor $r^{\frac{4}{3}}$. In the case of natural rainbows where, as Pernter indicated, the supernumerary bows were observed when the drops were large, we can not take into account the factor $r^{\frac{7}{3}}$ directly, because the intensity depends, at the same time, on the number of drops which are contained in a unit volume of space, and it is probable that when the radius of the drop is large the number of the drops is small. For instance, let us take the cases $r=0.025$ cm. and $r=0.05$ cm., and suppose that the quantities of the drops per unit volume is equal in the two cases, so that the ratio of the numbers of the drops is $2^3:1$, and that the

intensity of the rainbow is proportional to the $\frac{2}{3}$ th power of the number of the drops. Then, the numbers in the curves in Pl. III and Pl. V are increased by $2^2(0.025)^{\frac{2}{3}}$ and $(0.05)^{\frac{2}{3}}$, or 1 and 1.26 respectively, and we see that the intensity curves of the former are sharper than those of the latter. Thus, the above result of observation is explained only by saying that there was a comparatively large quantity of drops. But, we have another cause on which the above observation must depend; namely, the imperfectness of Airy's theory for large values of θ . In the strict sense, we can not compare the corresponding supernumerary bows due to two drops of different sizes, because the value of θ being different, the approximation of Airy's and consequently of our theory is not the same in both cases. So far as Airy's theory holds good, we can say that the supernumerary bow due to large drops is less distinct; leaving out of consideration both the factor $r^{\frac{7}{3}}$ and the number of the drops.

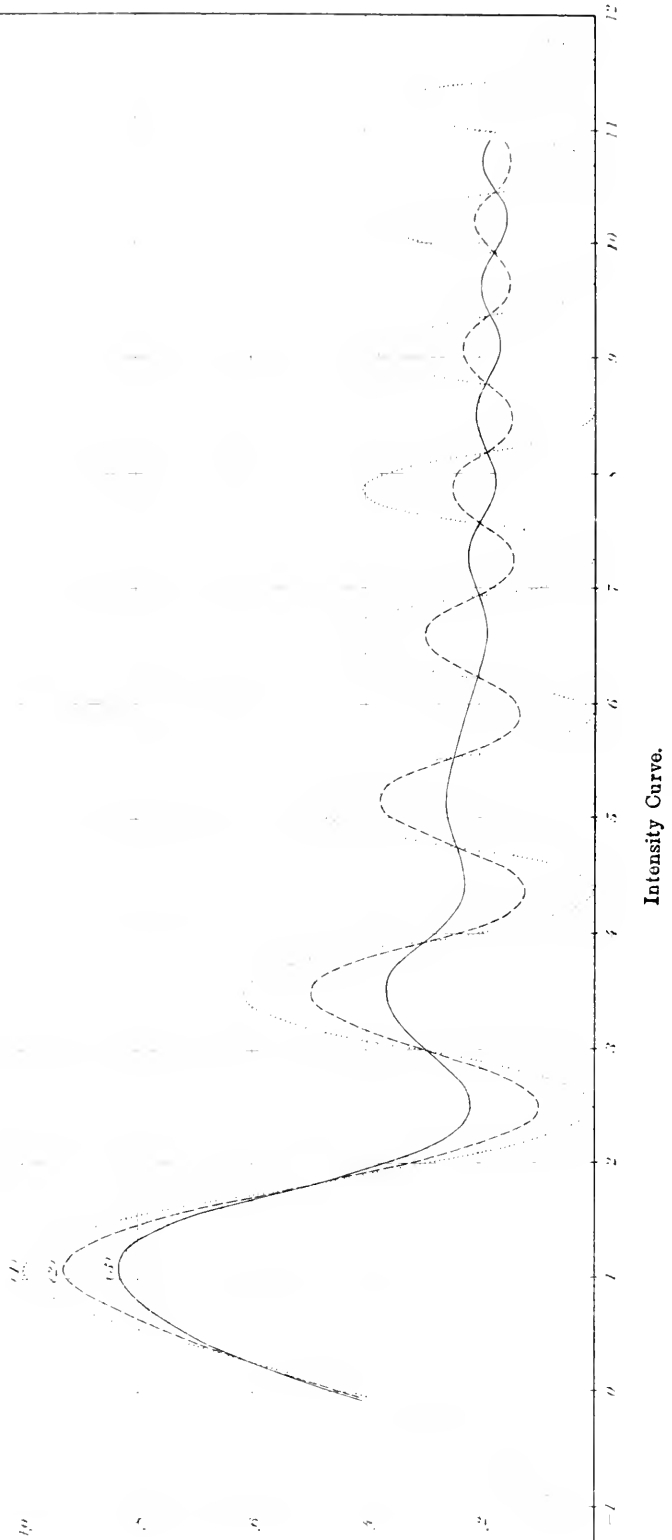
The above discussion only holds for supernumerary bows; on the contrary, the principal bow is more distinct for large drops, as Pl. III and Pl. V show. Thus a white rainbow is probably caused by small drops, or rather mixed drops of different sizes. In fact, in many cases in nature, it is absolutely important to consider the inequality of the size of the drops, though actual discussion of this point is almost impossible.

In conclusion, we have to thank Prof. Nagaoka for suggesting the problem and for giving kind advice during the course of our investigations.

Curve (1) represents Airy's value of f^2 .

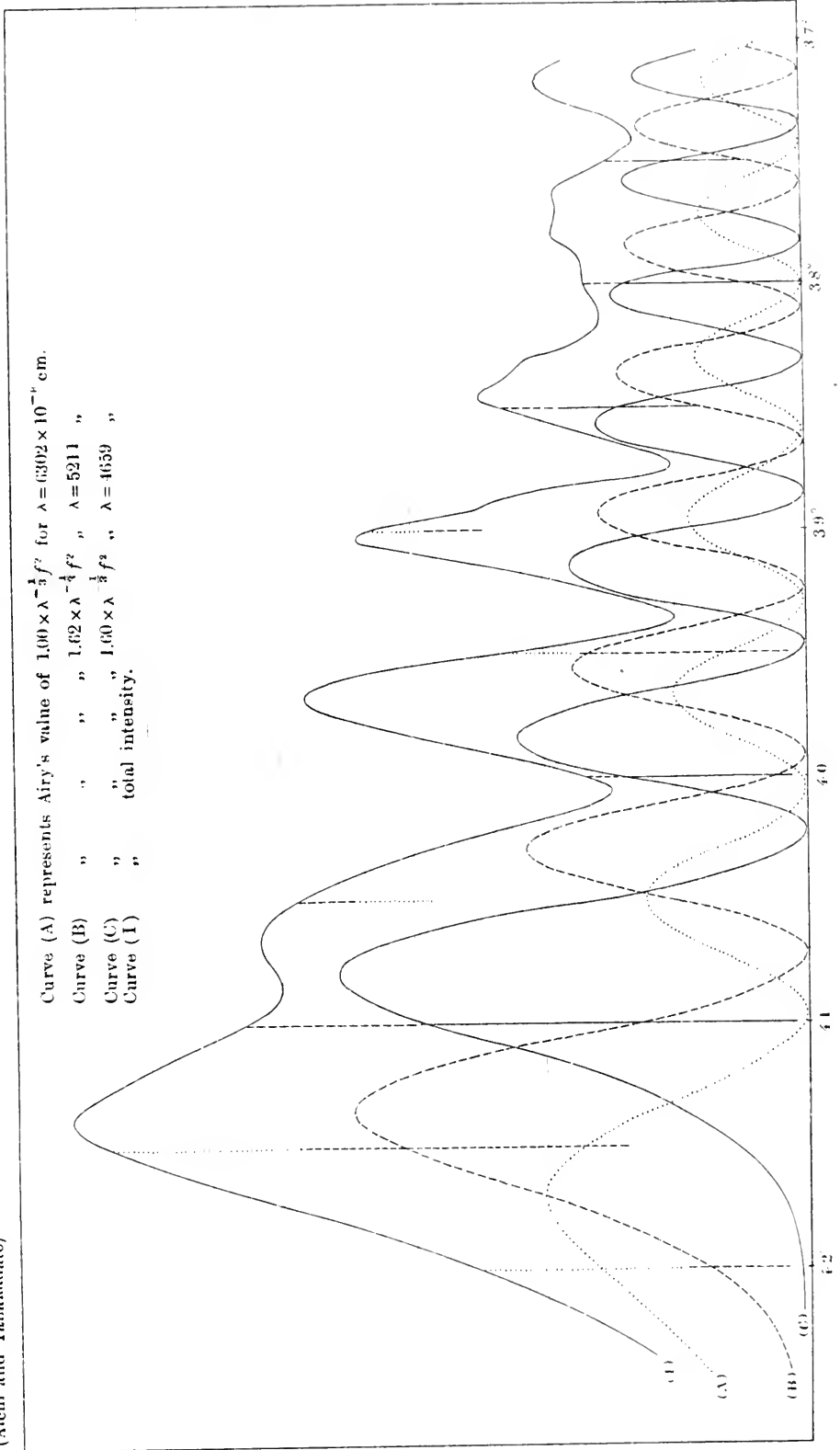
Curve (2) " " F_1 for circular source $2\phi = 32'$, $\lambda = 5893 \times 10^{-8}$ cm, $r = 0.025$ cm.

Curve (3) " " F_2 " " " " $r = 0.05$ cm.



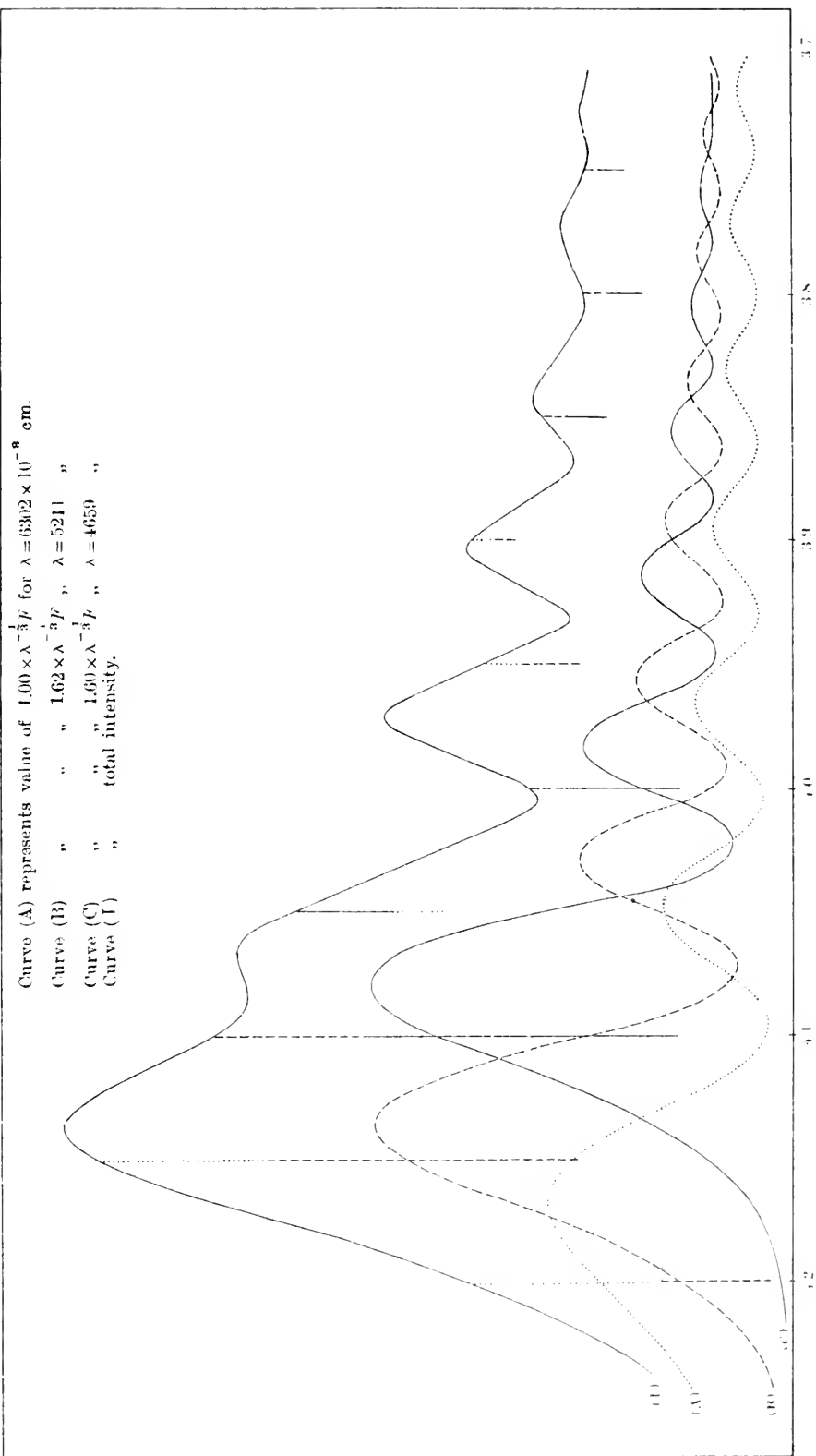
(Aiehi and Tanakadate)

Curve (A) represents Airy's value of $1.00 \times \lambda^{-\frac{1}{2}} f^2$ for $\lambda = 6302 \times 10^{-10}$ cm.
Curve (B) " " " $1.62 \times \lambda^{-\frac{1}{2}} f^2$ " $\lambda = 5211$ "
Curve (C) " " " $1.60 \times \lambda^{-\frac{1}{2}} f^2$ " $\lambda = 4639$ "
Curve (I) " " total intensity.



Intensity Curves for Primary Colours (Point Source, $r = 0.025$ cm).

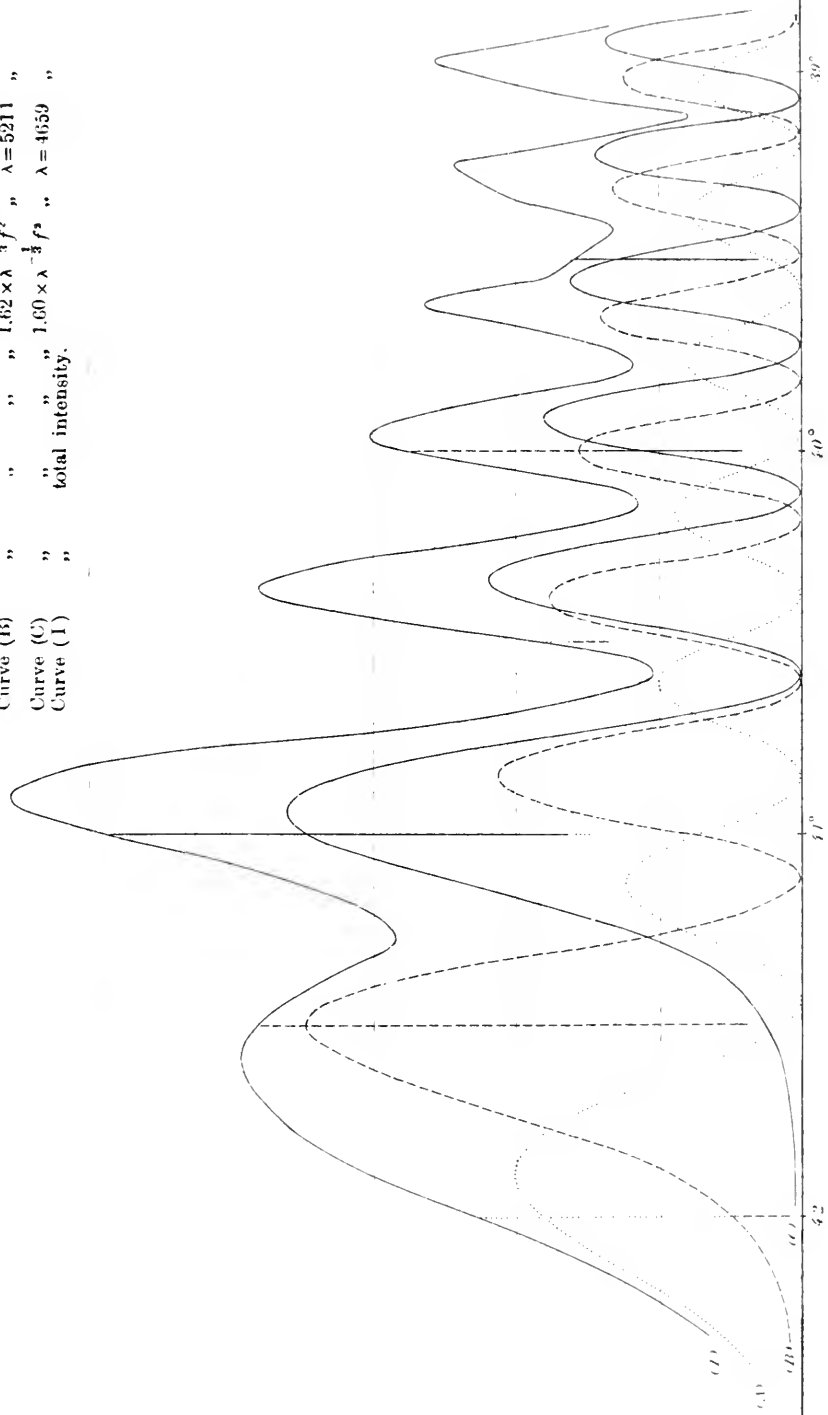
(Aichi and Tanakadate)



Intensity Curves for Primary Colours (Circular Source $2\Phi = 32'$, $r = 0.025$ cm.)

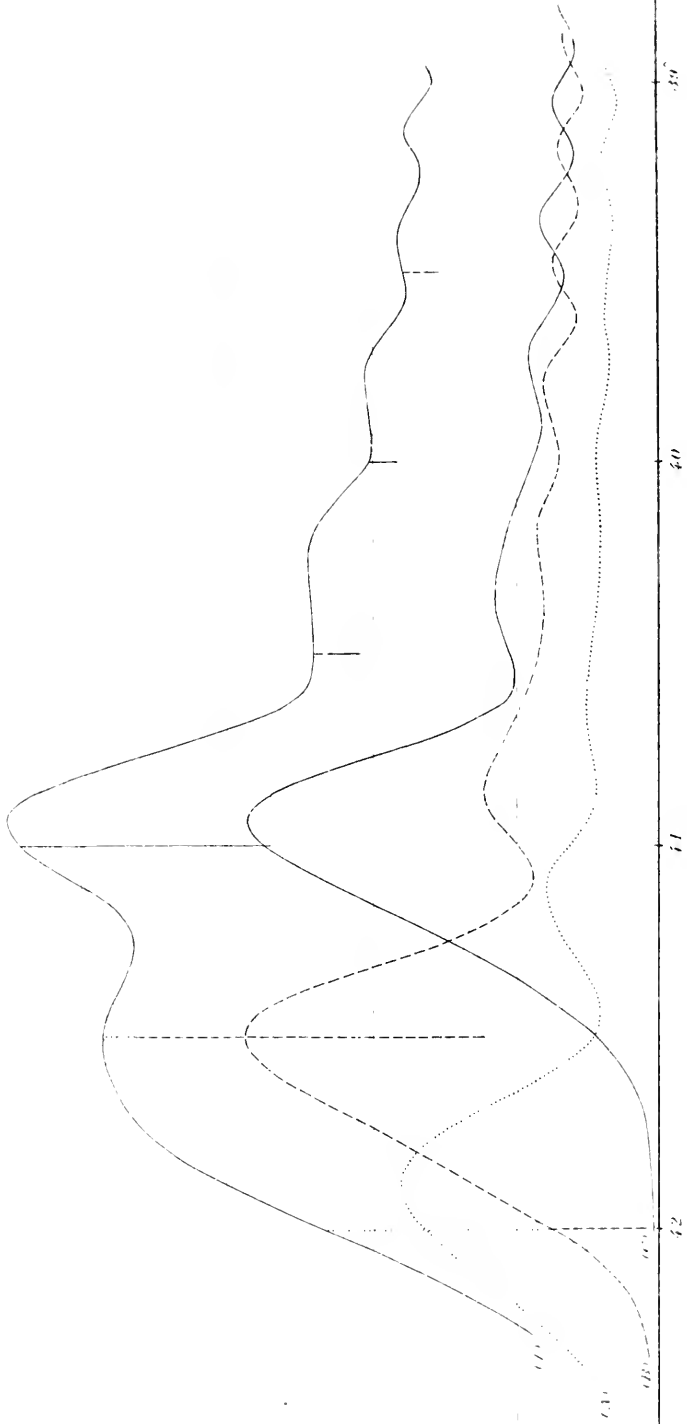
(Aichi and Tanakadate)

Curve (A) represents Airy's value of $1.00 \times \lambda^{-\frac{2}{3}} f^2$ for $\lambda = 6302 \times 10^{-8}$ cm.
 Curve (B) " " " $1.62 \times \lambda^{-\frac{2}{3}} f^2$ " $\lambda = 5211$ "
 Curve (C) " " " $1.60 \times \lambda^{-\frac{2}{3}} f^2$ " $\lambda = 4659$ "
 Curve (I) " " total intensity.



Intensity Curves for Primary Colours (Point Source, $r=0.05$ cm).

Curve (A) represents value of $1.00 \times \lambda^{-\frac{1}{3}} f$ for $\lambda = 6302 \times 10^{-9}$ cm
 Curve (B) " " $1.62 \times \lambda^{-\frac{1}{3}} f$ " $\lambda = 5211$ "
 Curve (C) " " $1.60 \times \lambda^{-\frac{1}{3}} f$ " $\lambda = 4659$ "
 Curve (I) " total intensity.



Intensity Curves for Primary Colours (Circular Source $2\phi = 32'$, $\tau = 0.05$ cm.).

On the Change of Elastic Constants of Ferromagnetic Substances by Magnetization.

By

CORRIGENDA.

Page 1, *for* plate I-X *read* plate I-VII.

The elastic constants of a substance in a magnetic field is here defined as the ratio of the stress applied to the strain caused thereby, the magnetic force constantly acting on the substance. The change of elasticity is then the difference of this ratio, when the magnetic field is on, and when it is off. In the case of ferromagnetic substances, for which the hysteresis is considerable, the change of elasticity so defined may, or may not coincide with that of the same ratio, when the stress is first applied and then the field. However, little attention seems to have hitherto been paid to this point. Thus, in many* of the experiments hitherto made regarding the change of elastic con-

*) Guillemin, C. R. **22**, 264 and 432, 1846. J. S. Stevens and H. G. Dorsy, *Phy. Rev.* (2) **9**, 116, 1899. G. Wiedemann, *Electricität* III, 796. C. Barus, *Amer. Jour.*, **34**, 175, 1887; *Phy. Rev.* XIII, 257, 1901. Day, *Electrician*, **39**, 480, 1897. J. S. Stevens, *Phy. Rev.* (3) **10**, 111, 1900. K. Honda and S. Shimizu, *Jour. Sc. Coll.*, Art. 12 and 13, Vol. XVI, 1902.

stants by magnetization, the right order of properly applying the stress and the field was inverted. In some experiments,* the effect of tension on the magnetic elongation was observed, and the change of the modulus of elasticity was deduced on the assumption that the effect was due to the change of elasticity by magnetization. The acoustical method† used by several experimenters is also an indirect one, and unsuitable for any accurate determinations. In H. Rensing's experiment‡, Kundt's tube was used; but the field in which the bar was placed, was far from being uniform.

Our present experiments were undertaken with the main object of measuring the change of elastic constants of the same specimen by the direct as well as the indirect method and comparing the results thus obtained: the specimen to be tested being placed in a nearly uniform field.

If ξ be the length or the angle of twist of the specimen, S the applied tension or couple respectively, and H the magnetic field, we have the relation

$$\frac{\partial}{\partial H} \left(\frac{\partial \xi}{\partial S} \right) = \frac{\partial}{\partial S} \left(\frac{\partial \xi}{\partial H} \right) \dots \dots \dots (1)$$

provided the change is independent of the order of applying the field and the stress. Thence we have

$$\left(\frac{\partial \xi}{\partial S} \right)_H - \left(\frac{\partial \xi}{\partial S} \right)_0 = \frac{\partial (\xi_H - \xi_0)}{\partial H} \dots \dots \dots (2)$$

If M be the modulus of elasticity or that of the rigidity respectively,

* J. Bock, *Wiel. Ann.* **54**, 442, 1895; *Phil. Mag.* (5) **39**, 548, 1895. K. Tangl, *Ann. der Phys.* **6**, 34, 1901. K. Honda and S. Shimizu, *loc. cit.*

† J. Wartmann, *Ann. de Chim. et de Phys.* **24**, 360, 1848. Trèves, *C. R.* **67**, 321, 1868; *Archives des Soc. Nat. N. S.* **33**, 74, 1868. Maurain, *C. R.*, **121**, 248, 1895.

‡ J. Rensing, *Ann. der Phys.* **14**, 363, 1904.

$$\frac{\partial \tilde{\xi}}{\partial S} = \frac{c}{M},$$

where c is a constant depending on the dimensions of the specimen. Hence we have finally

$$\begin{aligned} \frac{1}{M_H} - \frac{1}{M_0} &= \frac{1}{c} \frac{\partial(\tilde{\xi}_H - \tilde{\xi}_0)}{\partial S} \\ &= \frac{\frac{\partial(\tilde{\xi}_H - \tilde{\xi}_0)}{\partial S}}{M_0 \frac{\partial \tilde{\xi}_0}{\partial S}}, \end{aligned}$$

or
$$\frac{M_H - M_0}{M_H} = \frac{\partial M}{\partial S} = - \frac{\frac{\partial(\tilde{\xi}_H - \tilde{\xi}_0)}{\partial S}}{\frac{\partial \tilde{\xi}_0}{\partial S}} \dots\dots\dots(3)$$

Thus the change of elasticity may be calculated from the effect of tension on the magnetic elongation; and that of rigidity, from the change of twist caused by magnetization, provided relation (1) holds.

The validity of (3) depends upon relation (1), which is usually employed in the theory of magnetostriction. It was thought, therefore, that it would be interesting to test experimentally how far the relation actually holds. Accordingly the present investigation was carried out in the following order:—

I. Experiments on the change of elasticity:

- (a) Measurement of the change of elasticity by the elongation method.
- (b) Measurement of the modulus of elasticity.
- (c) Comparison of the results with those of the flexure method.

II. Experiments on the change of rigidity:

- (a) Measurements of the change of rigidity by the oscillation method.

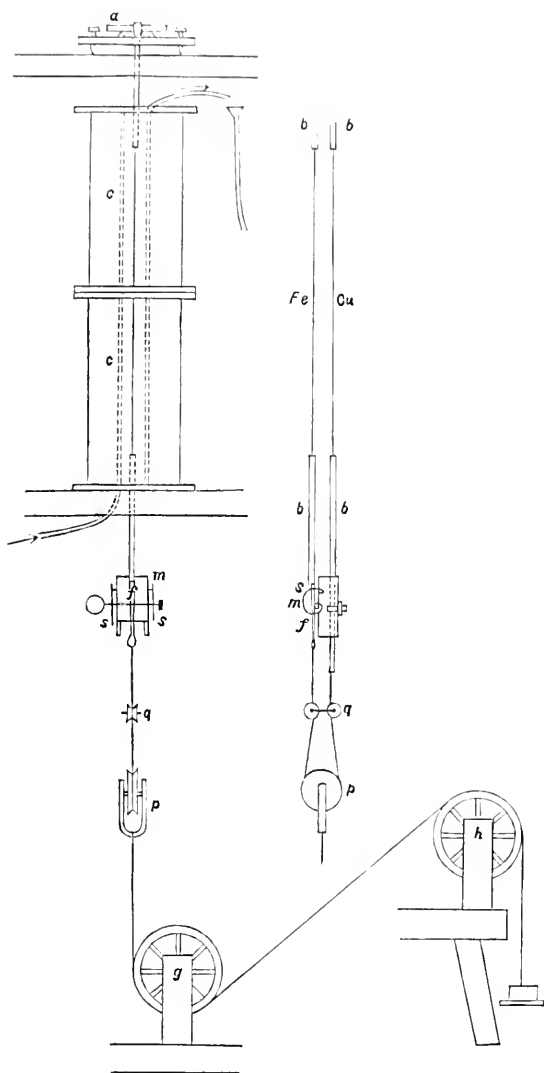
- | | | |
|-----|-------|-------------------------|
| (b) | Ditto | by Barus's method. |
| (c) | Ditto | by the ordinary method. |

The specimens tested in the present experiment were Swedish iron, tungsten steel, nickel, and nickel steels of different percentages. They were generally tested in the form of wires. For the change of rigidity, the rod was also used in the case of nickel and iron.

§ 2. EXPERIMENTS ON THE CHANGE OF ELASTICITY BY MAGNETIZATION.

(a) Measurement of the change of elasticity by the elongation method.

Since the elongation due to the change of elasticity is a small fraction of the total elongation, it was desirable to devise some differential method. For this purpose, the elastic elongation at no field was compensated by that of a non-magnetic wire, and the differential elongation due to magnetic field was observed. As shown in the annexed figure, the magnetic wire to be tested and the compensating copper wire were hung side by side in the vertical magnetizing coil *cc*. To both ends of the wires were brazed brass rods *bb*, whose elongation could be neglected. The upper rods were hung separately on two horizontal brass beams *aa'* resting on pairs of knife-edges, the distance between which could be adjusted at will. To the lower rod attached to the copper wire, a light carriage *m* for a mirror system was clamped. Two fine spiral springs *ss* of german silver attached to the sides of the carriage, supported horizontally the axis of the light mirror with a suitable counterpoising. The lower rod for the magnetic wire carried a flexible band *f* made of a bundle of very



fine copper wires, which pressed the axis of the mirror lightly upon the plane vertical side of the carriage. To the lower ends of these rods, a flexible silk cord was attached; a pulley *p* hanging in this cord was pulled vertically downward by a weight. The friction-wheel *q* served to adjust the distance between the two vertical wires. Instead of hanging the weight directly, a system of pulleys *gh* was used in order to avoid any injurious shock accompanying the loading and unloading of the wires. When the elongations of the two wires due to tension were exactly equal, there was

of course no rotation of the axis of the mirror. If, however, the compensation were disturbed in any way, the rotation could be observed in the usual manner by means of a vertical scale and a telescope.

To increase the sensitiveness of the arrangement, a wire about

74 cm. long was used; for want of a sufficiently long coil, two coils of the same dimensions were used, placing the one above another. The length of each coil was 39.90 cm., the internal diameter 5.80 cm., and $4\pi n = 393.5$. The air gap between the two coils was only 1.7 cm., so that the heterogeneity of the field in this space was inconsiderable. The wire to be tested then lay nearly in a uniform field.

The compensating copper wire was chosen of such dimensions as to produce an elongation nearly equal to that of the specimen. The final compensation was always made by properly adjusting the distance between the two knife-edges supporting the horizontal beams, from which the wires were suspended. A certain weight was added to the pan, or removed from it, and the distances of the knife-edges were adjusted, until either the addition or removal produced no rotation of the mirror. Since the elastic elongation was not exactly a linear function of the tension applied, a compensated system for a given initial and additional weight caused a rotation of the mirror for a different initial weight and the same additional weight. Hence the compensation was made anew for every initial weight, 1 kilogram always being used for the applied weight. It was, however, a matter of no great ease to obtain an exact compensation. Hence the slight deflection in no field was always recorded, and taken into account in the calculation of the deflection due to the change of elasticity by magnetization. To prevent shocks in putting on the additional weight, the face of the initial weight was covered by a mat of cotton wool. In this way, the reading of the deflection was greatly facilitated.

In the above arrangement, the rotation of the mirror caused by a change of temperature is very small, as it is affected only

by the relative expansion of the specimen and the compensating wire. But to avoid the effect of heating as much as possible, the coil was waterjacketed.

To increase the sensitiveness of the arrangement, a long scale distance of 7.23 m. was used. The scale was graduated on a ground glass, and illuminated from behind by a mantled gas flame. The telescope was placed in front of the apparatus and near the rotating mirror; consequently the line joining the centers of the scale and the mirror deviated slightly from the line of sight of the telescope. In this way, the scale at such a long distance could be read to a tenth of a millimeter with the observing telescope.

If the specimen undergoes a differential elongation δl , a rotation $\delta\varphi$ of the axis is produced, such that $\delta\varphi = \delta l/2r$, where r is the radius of the axis. If the scale distance be d and the reading on the scale corresponding to the elongation δl be n , we have

$$\delta\varphi = \frac{n}{2d} ; \quad \text{hence} \quad \delta l = \frac{rn}{d}$$

In our case, $2r = 1.61$ mm., so that a deflection amounting to one division of the scale in the field of the telescope corresponds to an elongation of 4.47×10^{-8} per unit length of the specimen. The sensitiveness of the apparatus was therefore about 10 times greater than that of the apparatus used by many previous investigators.

The magnetizing current supplied by a set of secondary batteries was measured by a Siemens-Halske ammeter, which was occasionally compared with a Kelvin ampere-balance.

The present arrangement also enabled us to measure the magnetic change of length of the specimen under constant tension

by applying a magnetic field to the specimen and observing the deflection of the mirror corresponding to different fields.

Our procedure in the experiment was usually as follows:— The wire to be tested was first annealed for about 4 hours in a charcoal fire, and then gradually cooled. To avoid surface oxidation during the process of annealing, the wire was buried in a fine powder of charcoal, and sealed in an iron tube, which was placed in a furnace. In this way, a small quantity of carbon might enter into the wire, but the oxidation was quite inappreciable. Variation in the diameter of the wire caused by the oxidation was avoided in the above manner.

To either end of the wire thus annealed, was brazed the brass rod before mentioned, and the whole was suspended in position as shown in the foregoing figure. Then the mirror and pulley-systems were placed in position. For avoiding a continuous slight vibration of the mirror, as well as for the rapid damping of the vibration due to loading or unloading the wire, it was necessary that a glass rod fixed to a stand should come lightly in contact with the bifilar cords near the friction-wheel *q*. The addition or removal of a weight from the pan was occasionally observed to cause a lateral displacement of the image in the mirror; this was, however, easily effaced by adjusting the clamp of the carriage to the rod.

The magnetic change of length under constant tension was first measured. Since the hysteresis effect of tension on the length change was found to be considerable, the tension was varied cyclically between zero and its maximum value before beginning the experiment, in order to remove any initial effects.

According to the results of our experiments, the ascending branch in the curve of elongation due to tension, lies a little

above the descending one. In the following tables, the length changes under constant tension are results for the stage of increasing weights, taken after several cycles of loading and unloading. The usual processes of observation were followed. The wire was first loaded with the smallest weight, which was generally 1 kilogram; the demagnetization by reversals was then carefully effected. A series of gradually increasing currents was passed through the magnetizing coil, and the corresponding deflections of the scale were noted. The wire was then completely demagnetized, and the zero position of the scale tested. Another weight of 1 kilogram was added and demagnetized, and the same processes were repeated. In this way, a set of observations corresponding to the different weights was taken.

The change of elasticity was next measured. We applied an initial load to the pan, demagnetized the wire by reversals, added and removed a weight of 1 kilogram, and adjusted the compensation, until the deflection due to the additional weight was as small as possible. The demagnetization was then carefully effected. The small deflection due to the additional weight for no field was recorded. Then we applied a magnetizing field and observed the deflection due to the additional weight. After the demagnetization, the deflection due to the same load for no field was again tested. The difference between the two deflections for no field and for the magnetic field gives the change of elasticity due to magnetization, provided we know the total elongation caused by the additional weight of 1 kilogram. To avoid any accidental error in observing these deflections, the deflections for several cycles of loading and unloading were, in each case, recorded, and their mean was taken. The initial weight was next increased,

and the same procedure repeated. The compensation was always readjusted for different initial weight.

Our object was partly to test the validity of equation (3), and since the change of elasticity was considerably affected by tension, the initial and the additional tensions were so chosen as to exactly correspond to those in the experiments of the magnetic change of length under constant tension.

In the calculation of the percentage change of elasticity due to magnetization, the values of elasticity were taken from the results of our experiments specially undertaken for this purpose.

The specimens tested and their dimensions were as follows:—

Substances.	Length.	Diameter.
Pure nickel	73.25 cm.	0.928 mm.
Commercial nickel	71.90	0.930
Swedish iron	71.87	0.904
Tungsten steel	73.76	0.886
28.74 % nickel steel	73.80	0.964
50.72 % „ „	73.60	0.880
70.32 % „ „	73.25	0.892

The experimental results are given in the following pages.

NICKEL

(i) Pure Nickel. Figs. 1 and 2.

The change of length $\frac{\delta l}{l}$ by magnetization for different tensions T and external magnetic fields H are given in the following table and Fig. 1.

TABLE I.

 $t=9.08$.

$T=1540 \text{ gr./mm.}^2$		$T=2283 \text{ gr./mm.}^2$		$T=3021 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
2.1	+ 0.02	4.1	- 0.18	4.3	- 0.11
5.8	- 0.59	7.7	- 0.97	8.5	- 0.73
9.4	- 2.09	11.3	- 2.26	12.6	- 1.67
14.0	- 4.37	15.6	- 3.69	16.6	- 2.81
24.2	- 11.94	24.4	- 7.40	24.4	- 5.27
33.4	- 20.28	33.0	- 12.01	32.8	- 8.25
49.1	- 28.25	40.8	- 23.96	48.4	- 16.11
74.2	- 33.1	74.6	- 32.2	72.7	- 28.96
94.3	- 35.7	93.7	- 35.4	93.4	- 33.9
143.2	- 39.7	142.3	- 40.1	142.2	- 39.7
203	- 42.5	201	- 43.4	201	- 43.5
276	- 44.1	276	- 45.5	275	- 46.0
322	- 44.6	322	- 46.0	322	- 46.8
389	- 44.9	388	- 46.5	388	- 47.3

$T=3762 \text{ gr./mm.}^2$		$T=4498 \text{ gr./mm.}^2$		$T=5240 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
4.1	- 0.07	4.3	- 0.04	3.8	- 0.00
7.8	- 0.42	8.8	- 0.38	8.5	- 0.18
12.5	- 1.30	15.8	- 1.45	13.6	- 0.64
16.8	- 2.28	24.4	- 3.22	18.0	- 1.27
24.4	- 4.27	33.4	- 5.18	24.2	- 2.37
33.6	- 6.76	40.8	- 6.98	34.5	- 4.33
49.6	- 12.23	49.8	- 9.39	49.6	- 7.65
73.6	- 24.23	73.8	- 17.77	73.8	- 13.84
93.6	- 31.7	93.1	- 26.8	93.1	- 21.40
142.2	- 39.3	142.3	- 37.5	142.3	- 35.2
201	- 43.8	201	- 42.9	203	- 41.6
275	- 46.8	275	- 46.5	276	- 45.7
321	- 47.8	321	- 47.7	323	- 47.2
388	- 48.5	387	- 48.7	390	- 48.4

As may be seen from Fig. 1, nickel contracts by magnetization in a way similar to that given by many earlier experimenters; in weak fields, the contraction rapidly increases with the increasing field, but gradually tends to an asymptotic value, as the field attains a higher value. The increased tension decreases the amount of contraction for low fields, while for higher fields, it increases the contraction. Thus there exists a certain field in which the effect of the additional tension is null. This neutral point for two successive tensions, shifts toward the higher field, as the tension increases. In their general course, the curves are quite similar to those already obtained by Mr. S. Shimizu and one of us.³

The change of elasticity of nickel is given in the table below and in Fig. 2.

TABLE II.

 $\Delta T = \pm 743 \text{ gr./mm.}^2$ $t = 10.0^\circ \text{ C.}$

$T = 1540 \text{ gr./mm.}^2$		$T = 3021 \text{ gr./mm.}^2$		$T = 4498 \text{ gr./mm.}^2$	
H	$\frac{\partial E}{\partial H} \times 10^2$	H	$\frac{\partial E}{\partial H} \times 10^2$	H	$\frac{\partial E}{\partial H} \times 10^2$
4.5	— 0.05	9.3	— 0.54	11.6	— 0.40
10.4	— 1.59	19.5	— 1.67	25.0	— 1.24
25.0	— 8.41	34.1	— 3.98	51.0	— 3.31
31.3	— 12.15	49.9	— 8.41	70.3	— 6.11
37.7	— 14.40	64.3	— 12.22	99.6	— 9.90
50.3	— 7.10	71.1	— 11.06	106.3	— 8.18
71.5	— 3.10	90.9	— 6.19	129.4	— 5.43
118.2	— 0.42	131.8	— 2.43	191.9	— 3.21
196.7	+ 0.98	210	— 1.01	—	—
287	+ 2.20	288	— 0.61	277	— 1.72
406	+ 2.19	397	+ 0.27	390	— 0.83

³) K. Honda and S. Shimizu, Jour. Sci. Coll., Vol. XVI., Art. 9, 1932.

In the above table, WT denotes the weight applied or removed for studying the elongation of the specimen.

The coefficient of elasticity first decreases as the field increases, attains a minimum value, whence it begins to increase, at first rather abruptly and then gradually. The effect of tension is to drive the field corresponding to the minimum elasticity toward the higher field, and also to depress the absolute amount of decrease. For a weak tension, the elasticity increases by magnetization in fields higher than a certain field at which the change is zero. This field is displaced toward the higher field by the increasing tension.

The change of elasticity calculated from the effect of tensions upon the magnetic change of length is as follows:—

TABLE III.

$$WT=743 \text{ gr./mm.}^2$$

$T=1540 \text{ gr./mm.}^2$		$T=3021 \text{ gr./mm.}^2$		$T=4498 \text{ gr./mm.}^2$	
H	$\frac{\delta E}{E H} \times 10^2$	H	$\frac{\delta E}{E H} \times 10^2$	H	$\frac{\delta E}{E H} \times 10^2$
20	— 7.4	—	—	—	—
35	— 19.1	30	— 3.1	40	— 2.4
40	— 17.4	60	— 14.3	—	—
60	— 6.5	70	— 14.3	80	— 12.4
100	— 0.7	90	— 6.1	100	— 13.1
200	+ 2.4	150	0.0	130	— 7.6
300	+ 3.6	250	+ 1.2	200	— 3.8
380	+ 3.5	350	+ 2.5	300	— 1.6

Curves are also given in Fig. 2 in dotted lines. Comparing the above results with those directly observed, we notice at once, that the general course of the change of elasticity is quite similar

for both results, the fields in which the change is maximum, coinciding in a remarkable way. The amount of the change is generally greater in the present case than in the previous one.

(ii) **Commercial Nickel.** Figs. 3 and 4.

The change of length by magnetization is generally similar to that in pure nickel. But the effect of tension is much smaller and the field in which the effect of an additional tension is null does not differ so much for different tensions as in the former specimen. The results are given in Table IV and in Fig. 3.

TABLE IV.

$t=9.5^{\circ} \text{ C.}$

$T=1325 \text{ gr./mm.}^2$		$T=1962 \text{ gr./mm.}^2$		$T=2600 \text{ gr./mm.}^2$		$T=3239 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^2$
2.3	— 0.09	2.5	— 0.09	2.6	— 0.09	2.3	— 0.04
6.9	— 0.92	7.8	— 0.78	8.8	— 0.90	8.3	— 0.54
13.7	— 3.04	14.5	— 2.50	16.2	— 2.54	15.4	— 1.90
22.4	— 6.20	22.5	— 5.32	23.1	— 4.63	23.1	— 4.02
38.2	— 11.62	38.1	— 10.72	39.0	— 9.84	38.9	— 9.02
49.1	— 14.62	49.3	— 14.02	50.4	— 13.22	50.2	— 12.32
71.9	— 19.16	71.5	— 18.76	71.5	— 18.44	71.5	— 17.60
120.4	— 25.20	120.2	— 25.44	120.4	— 25.40	120.5	— 25.46
191.6	— 29.46	191.5	— 30.3	192.0	— 31.0	192.0	— 31.4
261	— 31.7	258	— 32.7	262	— 33.3	258	— 34.2
328	— 32.9	328	— 34.0	331	— 34.8	330	— 35.9
390	— 33.7	390	— 34.8	392	— 35.7	391	— 36.8

The change of elasticity is as follows. Curves are also given in Fig. 4 with full lines.

TABLE V.

$$JT = \pm 638 \text{ gr./mm.}^2$$

$$t = 8.^\circ 4 \text{ C.}$$

$T = 1326 \text{ gr./mm.}^2$		$T = 2600 \text{ gr./mm.}^2$		$T = 3874 \text{ gr./mm.}^2$	
H	$\frac{dE}{E_H} \times 10^2$	H	$\frac{dE}{E_H} \times 10^2$	H	$\frac{dE}{E_H} \times 10^2$
7.6	-0.65	67	-0.41	6.8	0.00
14.0	-1.24	109	-0.70	11.1	-0.53
22.9	-1.60	19.8	-1.34	24.6	-1.33
37.7	-1.90	32.6	-2.36	39.1	-2.26
52.1	-1.96	52.3	-2.87	51.6	-2.92
75.3	-1.48	77.8	-2.29	76.7	-3.26
123.2	-0.40	108.0	-1.72	105.7	-2.66
193.5	+0.45	194.0	-0.14	165.3	-1.33
271	+1.07	262	+0.70	260	-0.09
—	—	330	+0.99	331	+0.49
383	+1.42	397	+1.14	398	+0.78

Here the general aspect of the change is similar to that of the pure nickel. The amount of the change is, however, far less than in the previous specimen. The effect of tension is also to drive the maximum of the change toward higher fields, but not in such a decided way as in the case of pure nickel. Moreover, the increased tension increases the amount of the maximum change, up to the highest tension employed. These remarkable differences between the pure and the commercial nickel are probably due to the imperfect annealing rather than to the impurity

of the latter specimen, as it was slightly annealed with a gas flame.

The change of elasticity calculated from the tension effect on the magnetic change of length somewhat resembles in its aspect that for pure nickel, but the amount of the change is much smaller. The calculated values are given in Table VI and in Fig. 4 with dotted lines.

TABLE VI.

$$\Delta T = \pm 638 \text{ gr./mm.}^2$$

H	$T = 1326 \text{ gr./mm.}^2$	$T = 2600 \text{ gr./mm.}^2$
	$\frac{\partial E}{\partial H} \times 10^2$	$\frac{\partial E}{\partial H} \times 10^2$
10	-2.23	-0.96
20	-2.97	-1.75
40	-3.26	-2.42
70	-1.19	-2.23
100	+0.44	0
200	+1.78	+1.75
300	+2.97	—

Thus, in pure as well as in commercial nickel, we find a sensible deviation from relation (3).

SWEDISH IRON AND TUNGSTEN STEEL.

(i) Swedish iron. Figs. 5 and 6.

The change of length due to magnetization is given in Table VII and in Fig. 5.

TABLE VII.

 $t=9^{\circ}.2\ C.$

$T=1627\ gr./mm.^2$		$T=2410\ gr./mm.^2$		$T=3190\ gr./mm.^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
3.8	-0.02	3.8	-0.09	3.5	-0.10
8.1	+0.94	8.3	+0.64	8.6	+0.42
12.4	+1.44	12.8	+1.00	14.1	+0.66
17.5	+1.68	16.8	+1.10	17.7	+0.72
23.3	+1.78	22.3	+1.18	23.4	+0.74
35.3	+1.80	33.8	+1.18	35.4	+0.68
54.2	+1.60	52.5	+0.98	53.8	+0.44
78.2	+1.26	74.8	+0.62	78.0	+0.04
117.2	+0.56	113.3	-0.08	113.6	-0.60
185.0	-0.82	186.3	-1.54	187.8	-2.12
250	-2.10	252	-2.80	253	-3.40
318	-3.30	320	-3.94	322	-4.56
384	-4.34	385	-4.92	388	-5.56

$T=3974\ gr./mm.^2$		$T=4754\ gr./mm.^2$		$T=5535\ gr./mm.^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
3.3	-0.08	3.5	-0.10	3.2	-0.06
7.8	+0.20	8.4	+0.04	8.2	-0.09
13.4	+0.38	14.0	+0.12	12.4	-0.05
18.0	+0.42	17.4	+0.13	17.1	-0.05
23.3	+0.42	22.5	+0.11	22.3	-0.08
34.9	+0.34	33.9	+0.06	33.8	-0.21
51.2	+0.12	51.6	-0.18	52.0	-0.52
74.8	-0.29	74.8	-0.64	74.8	-0.94
112.9	-1.08	113.3	-1.44	112.9	-1.74
185.0	-2.54	186.0	-2.94	185.8	-3.24
249	-3.76	251	-4.20	250	-4.48
317	-4.90	317	-5.32	317	-5.62
382	-5.84	382	-6.30	380	-6.58

For small tensions, the change is an elongation in low fields, attains a maximum in a certain field, passes zero, and afterward is changed to a contraction. The maximum elongation decreases with the increasing tension, driving the zero toward the weak field; and beyond a certain tension, the length of the wire steadily contracts with the increase of the field. It seems also that the field corresponding to the maximum elongation slowly moves toward the weaker fields as the tension is increased. These results are in complete agreement with those obtained by former experimenters.

The change of elasticity for this sample was unexpectedly small, its amount being not very much greater than the limit of experimental error. The values obtained are given in Table VIII and in Fig. 6 with a full line.

TABLE VIII.

$JT=784 \text{ gr./mm.}^2 \quad t=11.^\circ 5 \text{ C.}$	
$T=1627 \text{ gr./mm.}^2$	
H	$\frac{\partial E}{E_H} \times 10^2$
37.1	+0.02
120.4	+0.20
404	+0.28

Thus, $\frac{\partial E}{E}$ is as a whole very small, and increases with the field tending to an asymptotic value.

On the other hand, the calculated values of $\frac{\partial E}{E}$ from the magnetic elongation are decidedly greater than those obtained by our direct method, as may be seen from Table IX, and Fig 6 in dotted lines. The difference is remarkable as well as interesting.

TABLE IX.

$$JT = \pm 784 \text{ gr./mm.}^2$$

	$T = 1627 \text{ gr./mm.}^2$	$T = 3190 \text{ gr./mm.}^2$	$T = 4754 \text{ gr./mm.}^2$
H	$\frac{\delta E}{E_H} \times 10^2$	$\frac{\delta E}{E_H} \times 10^2$	$\frac{\delta E}{E_H} \times 10^2$
10	0.9	0.6	0.4
20	1.4	0.8	0.5
40	1.6	0.9	0.8
70	1.7	1.0	0.9
100	1.7	1.1	0.8
200	1.7	1.1	0.8
300	1.4	1.1	0.8
350	1.4	1.0	0.8

(ii) Tungsten Steel. Figs. 7 and 8.

The elongation by magnetization increases at first rapidly, then slowly, and afterward gradually decreases. Tension decreases elongation regularly. The results are tabulated as follows:—

TABLE X.

$$t = 12^\circ.5 \text{ C.}$$

$T = 1693 \text{ gr./mm.}^2$		$T = 2509 \text{ gr./mm.}^2$		$T = 3322 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
10.0	0.03	9.0	0.03	9.5	0.04
13.8	0.09	13.1	0.08	13.5	0.09
19.4	0.60	19.5	0.64	19.5	0.57
24.9	1.39	25.2	1.46	25.2	1.32
42.2	2.72	42.8	2.62	42.7	2.39
64.5	3.26	65.5	3.16	64.9	2.88
96.2	3.56	97.4	3.48	97.0	3.15
167.2	3.72	168.8	3.60	168.0	3.24
246	3.63	246	3.48	245	3.13
330	3.48	333	3.26	331	2.92
399	3.28	402	3.11	400	2.78

$T=4136 \text{ gr./mm.}^2$		$T=5762 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
8.2	0.04	8.9	0.03
13.6	0.10	13.1	0.07
19.1	0.52	19.3	0.44
24.8	1.15	25.0	1.05
42.2	2.17	42.3	1.92
64.7	2.64	64.0	2.26
97.4	2.87	94.9	2.46
168.6	2.96	166.0	2.51
246	2.82	244	2.34
332	2.61	334	2.10
401	2.47	397	1.93

As in the case of Swedish iron, the change of elasticity is very small, gradually increasing with the field. Its amount does not much exceed the limit of experimental error, as given in table XI:—

TABLE XI.

$$JT = \pm 816 \text{ gr./mm.}^2$$

$$t = 10^\circ.8 \text{ C.}$$

$T=1692 \text{ gr./mm.}^2$		$T=4947 \text{ gr./mm.}^2$	
H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$
245	0.08	210	0.50
380	0.10	400	0.39

The calculated values of $\frac{\delta E}{E}$ are decidedly greater than those above given, as seen in Table XII and the dotted curves in Fig. 8.

TABLE XII.

$$JT = \pm 816 \text{ gr./mm.}^2$$

	$T = 1692 \text{ gr./mm.}^2$	$T = 4947 \text{ gr./mm.}^2$
H	$\frac{\partial E}{\partial H} \times 10^2$	$\frac{\partial E}{\partial H} \times 10^3$
50	—	0.4
100	0.2	0.5
200	0.3	0.6
300	0.5	0.6
400	0.5	0.7

Thus, in the case of iron and steel, relation (3) does not hold even approximately, when the tension is small. But as the tension is increased, the discrepancy becomes less.

NICKEL STEELS.

(i) 28.74 % nickel steel. Figs. 9 and 10.

The specimen first elongates rapidly and then almost proportionally with the field. The effect of tension is generally to depress the change of length. The general feature of the change may be seen in the following table and in Fig. 9.

TABLE XIII.

 $t=10^{\circ}.3.$

$T=1427 \text{ gr./mm.}^2$		$T=2115 \text{ gr./mm.}^2$		$T=2798 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
0.2	-0.01	0.3	-0.04	0.2	-0.01
0.6	-0.05	0.6	-0.09	0.6	-0.06
1.2	+0.13	1.1	+0.07	1.3	+0.13
2.0	+0.27	2.1	+0.26	2.2	+0.26
4.1	+0.52	4.2	+0.51	5.4	+0.49
8.9	+0.80	12.8	+0.84	15.3	+0.71
26.1	+1.11	25.4	+1.04	26.0	+0.85
43.9	+1.29	43.3	+1.22	43.4	+1.04
68.3	+1.52	68.1	+1.47	68.5	+1.30
113.6	+1.98	113.6	+1.93	114.1	+1.74
207	+2.87	206	+2.78	208	+2.66
303	+3.77	302	+3.71	305	+3.57
404	+4.67	404	+4.66	405	+4.50

$T=3487 \text{ gr./mm.}^2$		$T=4170 \text{ gr./mm.}^2$		$T=4856 \text{ gr./mm.}^2$	
H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$	H	$\frac{\delta l}{l} \times 10^6$
0.4	-0.02	0.2	0.00	0.2	0.00
0.8	0.00	0.6	-0.04	0.5	-0.02
1.5	+0.11	1.3	+0.05	1.3	+0.05
3.5	+0.26	4.2	+0.20	3.0	+0.13
8.5	+0.42	9.3	+0.32	8.0	+0.23
14.7	+0.50	15.2	+0.37	13.9	+0.29
25.6	+0.60	26.2	+0.48	25.8	+0.39
43.0	+0.77	44.2	+0.65	44.1	+0.56
68.1	+1.01	68.3	+0.88	68.7	+0.80
110.5	+1.40	113.9	+1.31	114.1	+1.24
204	+2.28	207	+2.17	207	+2.10
299	+3.15	304	+3.03	305	+3.01
397	+4.03	403	+3.93	405	+3.92

The observed values of $\frac{\partial E}{E}$ are generally small, but are rather greater than those for iron. The elasticity increases by magnetization in a manner similar to that of iron. An unconspicuous maximum is, however, observed in a high fields. Increased tension decreases the amount of the change; this makes the feature of the maximum conspicuous. The following table and the full lines in Fig. 10 show the results of our experiment.

TABLE XIV.

 $JT = \pm 688 \text{ gr./mm.}^2$ $t = 10.^\circ 2.$

$T = 1427 \text{ gr./mm.}^2$		$T = 2798 \text{ gr./mm.}^2$		$T = 4170 \text{ gr./mm.}^2$	
H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$
4.1	0.07	5.8	0.07	6.2	0.03
14.4	0.34	14.7	0.25	26.4	0.12
48.3	0.41	44.5	0.31	49.0	0.14
113.7	0.53	113.7	0.41	112.8	0.15
237	0.51	239	0.44	238	0.04
391	0.48	397	0.46	418	0.00

The values of $\frac{\partial E}{E}$ as calculated from the tension effect on the change of length differ from the above values rather considerably for slight tension; but they approach each other for high tension, as may be seen in Table XV and the dotted curves in Fig. 10. Here the change of elongation due to tension being very small, the calculated values of $\frac{\partial E}{E}$ are not very certain.

TABLE XV.

$$JT = \pm 688 \text{ gr./mm.}^2$$

	$T = 1427 \text{ gr./mm.}^2$	$T = 2798 \text{ gr./mm.}^2$	$T = 4170 \text{ gr./mm.}^2$
H	$\frac{\partial E}{\partial H} \times 10^2$	$\frac{\partial E}{\partial H} \times 10^2$	$\frac{\partial E}{\partial H} \times 10^2$
20	0.17	0.56	—
50	—	0.68	0.17
100	0.17	0.73	0.17
200	0.19	0.82	0.15
300	0.22	0.90	0.08
400	0.24	0.97	0.06

(ii) 50.72 % Nickel Steel. Figs. 11, 12, 13 and 14.

The change of length due to magnetization differs widely for different tensions. For slighter tensions, the wire generally elongates by magnetization, except at very weak fields, where it slightly contracts, a fact not observed in previous experiments.* The amount of the elongation increases, rapidly at first, and tends soon to an asymptotic value, as the field is increased. The increased tension depresses the elongation in a remarkable degree, so that beyond a certain tension, the change of length by magnetization changes its sign and becomes a contraction. The effect of tension, however, decreases uniformly with the increase of the tensions. The results are given in Table XVI, and graphically in Figs. 11 and 12.

*) H. Nagaoka and K. Honda, Jour. Sc. Coll. XIX. Art. 11, 1903.

K. Honda and S. Shimizu, Ibid. XX. Art. 6, 1905.

TABLE XVI.

 $t = 10^\circ \text{ o } C.$

$T = 890 \text{ gr./mm.}^2$		$T = 1713 \text{ gr./mm.}^2$		$T = 2538 \text{ gr./mm.}^2$		$T = 3360 \text{ gr./mm.}^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
0.2	- 0.09	0.3	- 0.13	0.2	- 0.03	0.2	- 0.01
0.6	- 0.44	0.6	- 0.30	0.7	- 0.11	0.7	- 0.01
1.0	- 0.52	1.1	- 0.13	1.2	+ 0.13	1.4	+ 0.12
1.4	- 0.06	1.8	+ 0.50	2.4	+ 0.83	3.2	+ 0.43
1.8	+ 0.66	3.4	+ 1.64	4.8	+ 1.57	—	—
3.8	+ 2.48	7.4	+ 3.67	8.6	+ 2.38	7.8	0.94
6.6	+ 4.37	14.3	+ 5.60	14.9	+ 3.19	15.8	1.39
15.6	+ 8.25	22.3	+ 6.90	22.7	+ 3.76	22.6	1.62
22.6	+ 9.85	35.4	+ 7.96	35.8	+ 4.23	35.3	1.85
35.6	+ 11.62	52.0	+ 8.51	52.6	+ 4.54	52.3	2.01
53.0	+ 12.49	70.4	+ 8.84	70.8	+ 4.76	70.4	2.12
70.8	+ 12.91	108.2	+ 9.43	108.2	+ 4.96	108.2	2.25
108.2	+ 13.41	177.4	+ 9.70	178.5	+ 5.15	178.0	2.36
241	+ 13.98	240	+ 9.87	242	+ 5.26	241	2.42
306	+ 14.10	302	+ 9.97	306	+ 5.33	304	2.46
390	+ 14.20	386	+ 10.08	391	+ 5.40	387	2.53

$T = 4184 \text{ gr./mm.}^2$		$T = 5003 \text{ gr./mm.}^2$		$T = 5828 \text{ gr./mm.}^2$		$T = 6652 \text{ gr./mm.}^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
0.2	- 0.02	0.2	- 0.01	0.2	- 0.01	0.2	- 0.01
0.3	- 0.07	0.7	- 0.09	0.6	- 0.04	—	—
1.2	- 0.02	1.4	- 0.11	1.5	- 0.10	1.0	- 0.07
3.4	+ 0.11	4.5	- 0.18	4.5	- 0.20	4.6	- 0.29
6.9	+ 0.26	—	—	8.0	- 0.29	—	—
11.9	+ 0.44	10.8	- 0.18	15.8	- 0.40	12.7	- 0.52
17.8	+ 0.55	22.6	- 0.16	35.7	- 0.50	22.6	- 0.61
22.8	+ 0.61	35.9	- 0.16	52.7	- 0.55	53.1	- 0.83
35.8	+ 0.73	70.8	- 0.18	108.7	- 0.67	83.5	- 0.95
71.2	+ 0.83	178.0	- 0.24	178.0	- 0.73	134.6	- 1.05
180.0	+ 0.93	262	- 0.25	241	- 0.78	224	- 1.13
307	+ 1.00	328	- 0.24	306	- 0.78	304	- 1.14
393	+ 1.07	390	- 0.22	391	- 0.77	388	- 1.14

The observed values of the change of elasticity are as follows. Curves are also given in Fig. 14 in full lines.

TABLE XVII.

$$JT = \pm 823 \text{ gr./mm.}^2$$

$$t = 11^{\circ}.3 \text{ C.}$$

$T = 890 \text{ gr./mm.}^2$		$T = 1713 \text{ gr./mm.}^2$		$T = 3360 \text{ gr./mm.}^2$		$T = 5003 \text{ gr./mm.}^2$	
H	$\frac{\partial E}{\partial H} \times 10^2$	H	$\frac{\partial E}{\partial H} \times 10^2$	H	$\frac{\partial E}{\partial H} \times 10^2$	H	$\frac{\partial E}{\partial H} \times 10^2$
0.8	0.09	0.7	0.05	1.6	0.20	1.8	0.00
3.9	0.96	4.1	1.08	6.2	0.64	6.5	0.23
13.2	3.67	13.4	2.82	12.8	0.99	13.1	0.39
26.0	5.55	24.6	3.76	24.5	1.18	24.0	0.56
41.3	6.89	39.2	4.72	40.7	1.42	40.2	0.68
60.5	7.56	67.5	5.19	62.4	1.51	62.4	0.86
93.8	8.05	103.3	5.40	103.3	1.66	104.3	0.99
153.5	8.26	187.6	5.57	159.5	1.76	161.0	1.03
271	8.39	276	5.68	276	1.81	277	1.07
388	8.65	386	5.68	386	1.89	387	1.13

The elasticity increases by magnetization, the increase tending soon to an asymptotic value, as the field increases. The effect of tension is to decrease it decidedly. At $T = 5003 \text{ gr./mm.}^2$, the change is reduced to about one-sixth of that at $T = 890$.

The calculated values of $\frac{\partial E}{\partial H}$ are generally greater than the above values, and the differences become smaller, as the tension is increased. With a tension of about 5 kg., this difference almost vanishes. The results are given in Table XVIII and in Fig. 14 with dotted lines.

TABLE XVIII.

$$JT = \pm 823 \text{ gr./mm.}^2$$

	$T = 890 \text{ gr./mm.}^2$	$T = 1713 \text{ gr./mm.}^2$	$T = 3360 \text{ gr./mm.}^2$	$T = 5003 \text{ gr./mm.}^2$
H	$\frac{\delta E}{E_H} \times 10^2$	$\frac{\delta E}{E_H} \times 10^2$	$\frac{\delta E}{E_H} \times 10^2$	$\frac{\delta E}{E_H} \times 10^2$
10	3.26	3.48	1.31	0.37
30	5.65	6.18	2.10	0.68
100	6.75	7.61	2.52	0.91
200	6.75	8.07	2.67	1.07
300	—	—	—	1.07
400	6.86	8.19	2.80	0.97

(iii) 70.32 % Nickel Steel. Figs. 15, 16, 17 and 18.

The change of length by magnetization resembles that for the former alloy, though the amount of the change is much smaller. Tension always decreases the elongation, the effect being smaller at greater tensions. Though the tension was increased up to 5686 gr./mm.^2 , we could not observe any indication that greater tensions would change the elongation into contraction. The elongation seems to tend gradually to zero with the increase of the load. These results are seen in Table XIX and Figs. 15, 16 and 17.

TABLE XIX.

 $t=9^{\circ}.2$.

$T=806 \text{ gr./mm.}^2$		$T=1671 \text{ gr./mm.}^2$		$T=2476 \text{ gr./mm.}^2$		$T=3277 \text{ gr./mm.}^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
0.3	-0.18	0.3	-0.18	0.2	-0.06	0.3	-0.09
0.6	-0.48	0.6	-0.45	0.6	-0.28	0.6	-0.21
1.0	-0.80	0.8	-0.60	1.0	-0.20	1.0	-0.11
1.4	+0.06	1.2	-0.09	1.4	+0.15	1.6	+0.11
1.8	+1.23	1.8	+0.61	—	—	3.0	+0.47
2.9	+2.59	3.0	+1.41	2.7	+0.70	4.9	+0.83
6.8	+5.08	4.9	+2.28	6.1	+1.60	10.0	+1.37
14.3	+6.70	17.0	+4.10	14.7	+2.46	17.2	+1.74
33.0	+7.68	34.1	+4.73	33.2	+3.01	33.2	+2.04
48.9	+7.90	44.3	+4.86	49.8	+3.16	49.8	+2.19
71.2	+8.03	66.6	+4.99	71.2	+3.25	71.2	+2.26
109.2	+8.12	107.8	+5.06	109.2	+3.33	108.7	+2.32
193.0	+8.21	185.8	+5.14	193.0	+3.42	191.8	+2.40
287	+8.25	283	+5.20	287	+3.45	286	+2.44
391	+8.35	364	+5.27	392	+3.49	389	+2.48

$T=4081 \text{ gr./mm.}^2$		$T=4882 \text{ gr./mm.}^2$		$T=5686 \text{ gr./mm.}^2$	
H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$	H	$\frac{\partial l}{l} \times 10^6$
0.2	-0.01	0.2	-0.03	0.2	-0.01
0.6	-0.17	0.6	-0.13	0.7	-0.09
1.1	-0.05	0.9	-0.08	1.0	-0.04
1.9	+0.09	1.3	-0.04	1.9	+0.05
2.5	+0.23	2.7	+0.18	3.6	+0.20
4.3	+0.48	7.2	+0.53	7.3	+0.40
7.3	+0.82	16.0	+0.84	16.2	+0.64
15.9	+1.21	33.4	+1.08	33.2	+0.90
33.5	+1.49	49.5	+1.19	49.8	+0.98
71.2	+1.69	71.2	+1.26	71.5	+1.05
109.2	+1.76	108.7	+1.32	109.2	+1.11
192.5	+1.85	192.8	+1.38	192.5	+1.16
288	+1.88	288	+1.42	287	+1.20
392	+1.93	394	+1.44	391	+1.24

The observed change of elasticity is generally similar to that for 50.72 % Ni, but less in its amount, as shown in Table XX and in full lines in Fig. 18.

TABLE XX.

 $JT = \pm 805 \text{ gr./mm.}^2$ $t = 9^{\circ}.2 \text{ C.}$

$T = 806 \text{ gr./mm.}^2$		$T = 1671 \text{ gr./mm.}^2$		$T = 3277 \text{ gr./mm.}^2$		$T = 4882 \text{ gr./mm.}^2$	
H	$\frac{\delta E}{E_H} \times 10^3$	H	$\frac{\delta E}{E_H} \times 10^3$	H	$\frac{\delta E}{E_H} \times 10^3$	H	$\frac{\delta E}{E_H} \times 10^3$
0.7	-0.14	0.7	-0.08	0.7	+0.18	0.6	-0.01
—	—	3.0	+1.17	2.6	0.40	0.8	+0.05
6.6	+2.45	5.3	1.92	4.7	0.53	3.8	0.30
9.7	3.57	9.6	25.2	12.0	1.07	12.0	0.45
19.9	4.13	41.1	3.33	26.1	1.35	25.1	0.60
41.8	4.51	68.9	3.38	53.4	1.42	52.7	0.68
70.8	4.71	136.3	3.45	98.8	1.55	98.8	0.70
177.3	4.92	226	3.72	193.0	1.50	192.6	0.70
260	4.92	309	3.69	285	1.57	284	0.78
386	4.92	388	3.74	393	1.53	393	0.70

The calculated values of $\frac{\delta E}{E}$ are generally greater than the above values, the difference being less for greater tensions, as seen in Table XXI and Fig. 18 with dotted lines. The difference almost vanishes for a tension of 3 kg.

TABLE XXI.

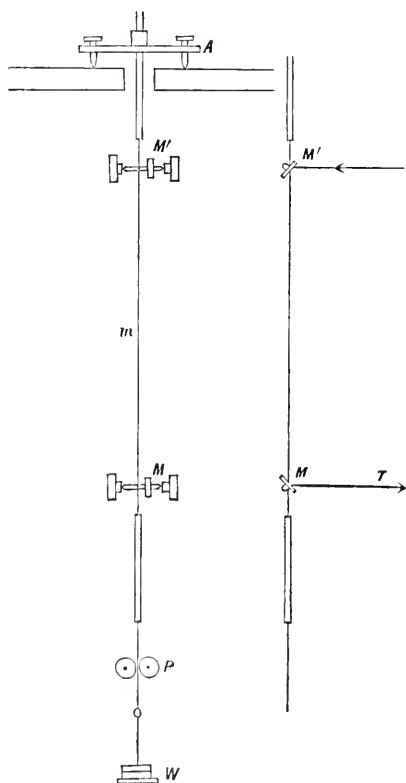
 $JT = \pm 805 \text{ gr./mm.}^2$

	$T = 806 \text{ gr./mm.}^2$	$T = 1671 \text{ gr./mm.}^2$	$T = 3277 \text{ gr./mm.}^2$	$T = 4882 \text{ gr./mm.}^2$
H	$\frac{\delta E}{E_H} \times 10^3$	$\frac{\delta E}{E_H} \times 10^3$	$\frac{\delta E}{E_H} \times 10^3$	$\frac{\delta E}{E_H} \times 10^3$
5	4.09	2.40	0.75	0.32
10	6.31	3.12	1.00	0.45
100	7.13	4.25	1.45	0.55
200	7.13	4.28	1.37	0.55
300	7.15	4.29	1.45	0.53

From the above results for nickel steels, we may conclude that for small tensions, the change of elasticity is considerably less than that calculated from the tension effect on the magnetic change of length. But the difference between the two becomes less and less as the tension is increased, almost vanishing for great tensions.

(b) **Measurement of the Coefficient of Elasticity.**

Since it was necessary, in the calculation of $\frac{\partial E}{E}$, to know the coefficient of elasticity in no field, a special arrangement was devised for this purpose.



Referring to the figure, m is the specimen, at the ends of which brass rods of moderate diameter are brazed. The upper rod is clamped to the tripod A resting on a rigid wooden frame. To the lower rod, is attached a flexible cord, which passing through the inter-space between the grooves of two friction wheels P fixed

to a stand, carries the scale pan for the weight W . Near the upper and lower ends, the specimen touches the horizontal axes carrying two mirrors M and M' respectively. The axes are so pivoted at their ends, that they rotate with almost no friction. S is a vertical glass scale illuminated from behind; its image formed by successive reflexions in M and M' is observed by a telescope T . If the load on the pan causes the elongations $\delta l'$ and δl respectively at M' and M , the rotations of the axes are given by

$$\varphi' = \frac{\delta l'}{r} \quad \text{and} \quad \varphi = \frac{\delta l}{r},$$

where r is the common thickness of the two axes. Again, if n' and n be the deflections of the scale due to separate rotations φ' and φ respectively, we have

$$\varphi' = \frac{n'}{2d} \quad \text{and} \quad \varphi = \frac{n}{2(d+a)},$$

where $d = MS$ and $a = MM'$. The actual deflection observed is $s = n - n'$.

$$\text{Now} \quad \delta l - \delta l' = r(\varphi - \varphi')$$

$$= \frac{rs}{2d} \left\{ 1 - \frac{a}{d} \left[1 + \left(\frac{n'}{s} - \frac{a}{d} \right) \left(1 - \frac{a}{d} \right) \right] \right\}.$$

In our experiments,

$$d = 624.5 \text{ cm.}, \quad a = 65.83 \text{ cm.}, \quad r = 0.795 \text{ mm.},$$

$$\text{and} \quad \frac{a}{d} = 0.1054.$$

Since n' was very small compared with s , and $\frac{n'}{s}$ appears as a small correction, it was sufficient for our purposes to determine n' roughly only once for a specimen throughout the sets of observations. This was easily done by directing the telescope to M' and

reading off the deflexion. Usually n' did not exceed 7 divisions of the scale, while s was greater than 90 divisions.

To prevent shocks by loading, the face of the initial weight was covered with a mat of cotton wool. The wire to be tested was surrounded by a tube of paper to prevent disturbance due to air-current.

Denoting the weight, by which the elongation $\delta l - \delta l'$ is produced, by P , we have for the coefficient of elasticity

$$E = \frac{\frac{P}{A}}{\frac{\delta l - \delta l'}{a}},$$

where A is the section of the wire. P in our experiments was 100 grams, which gave a deflection of more than 90 divisions of the scale. To test the working of the present apparatus, 10, 50 and 100 grams were loaded with the following results:—

TABLE XXII.

 $t = 12^{\circ} \text{ C.}$

Weight.	Tungsten Steel.	Nickel.	28.74 % Ni.
10 <i>gr.</i>	9.7 <i>div.</i>	9.1 <i>div.</i>	9.2 <i>div.</i>
50	48.1	47.3	46.3
100	96.2	96.0	92.9

Thus the proportionality is nearly satisfied up to 100 grams; this also shows that the friction at different parts of the arrangement is negligibly small.

The coefficient of elasticity differed slightly for different initial tensions, and moreover underwent more or less hysteresis due to the previous load. In our experiments, the weights were

varied from 1 to 7 kilograms, and then again down to 1 kilogram. The results are tabulated in the following table:—

TABLE XXIII.

 $t = 12^{\circ} \text{ C.}$

Pure nickel.		Commercial nickel.		Swedish iron.		Tungsten steel.	
$gr./mm.^2$	$E \times 10^{-12}$	$gr./mm.^2$	$E \times 10^{-12}$	$gr./mm.^2$	$E \times 10^{-12}$	$gr./mm.^2$	$E \times 10^{-12}$
1599	1.708	1376	1.818	1689	1.802	1758	1.928
3080	1.760	2651	1.972	3254	1.883	3386	1.938
4557	1.835	3923	2.049	4815	1.916	5011	1.938
6040	1.854	5199	2.125	6380	1.947	6640	1.955
7523	1.867	6477	2.152	7947	1.955	8272	1.949
9003	1.887	7750	2.193	9511	1.962	9900	1.951
10480	1.902	9023	2.212	11700	1.968	11523	1.945
7523	1.888	—	—	7947	1.935	8272	1.937
4557	1.851	5199	2.146	4815	1.919	5011	1.923
1599	1.739	1376	1.851	1689	1.788	1758	1.914

28.74 % Ni.		50.72 % Ni.		70.32 % Ni.	
$gr./mm.^2$	$E \times 10^{-12}$	$gr./mm.^2$	$E \times 10^{-12}$	$gr./mm.^2$	$E \times 10^{-12}$
1480	1.570	1780	1.376	1500	1.866
2850	1.619	—	—	—	—
4220	1.643	5070	1.551	4260	1.982
5600	1.667	—	—	—	—
6970	1.677	8370	1.621	7030	1.996
8340	1.693	—	—	—	—
9710	1.702	11650	1.619	9800	1.992
6970	1.675	8370	1.567	7030	1.986
4220	1.666	5070	1.548	4260	1.961
1480	1.591	1780	1.377	1500	1.864

The mean curves corresponding to these numbers are given in Figs. 19, 20, 21, 22, 23, 24 and 25. They are drawn in a very exaggerated scale. They show distinct hysteresis; in three of them, the ascending branch lies below the descending one, while in the others, the case is reversed. In commercial nickel, the increase of elasticity is the greatest; in tungsten steel, it is the least. In 50.72 % Ni. and 70.32 % Ni., the elasticity seems to attain a vague maximum at a high tension.

In the calculation of $\frac{\partial E}{\partial T}$ for different tensions, the values of E for corresponding tensions were employed. This was absolutely necessary, since for different tensions, E changed more than 10 % in many of the specimens.

(c) **Comparison of the results with those obtained by the flexure method.**

In a previous paper by Messrs. S. Shimizu, S. Kusakabe and one of us, the change of elasticity of magnetic bars, as determined by the flexure method is given. It is highly interesting to compare the results with those obtained by our elongation method.

In the flexure method, we observed a slight change of flexure by magnetization when there was no suspended weight; this perhaps arises from the initial bending of the specimen due to its own weight. In subsequent experiments of the kind, it was thought preferable to subtract this initial change of flexure from that of flexure due to a suspended load. We have therefore recalculated the former results, as shown in Table XXIV and in Figs. 26, 27 and 28.

TABLE XXIV.

SOFT IRON.				NICKEL.			
$T=500\text{ gr.}$		$T=2540\text{ gr.}$		$T=183\text{ gr.}$		$T=727\text{ gr.}$	
H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$
18.8	-0.03	20.1	+0.26	10.5	-0.22	10.0	-0.19
26.1	+0.56	26.9	+0.55	16.9	-0.79	16.7	-0.72
29.0	+0.77	33.9	+0.76	24.8	-0.96	21.9	-0.95
36.2	+0.89	52.9	+0.91	34.5	-1.52	26.4	-0.98
59.0	+1.01	69.4	+0.97	48.1	-0.53	39.6	-0.75
133.4	+1.04	129.0	+0.99	68.2	+0.11	68.2	+0.08
231	+1.04	212	+1.00	—	—	117.3	+1.35
291	+1.04	290	+1.02	240	+2.64	218	+2.57
383	+1.04	398	+1.07	376	+3.01	377	+3.16
				496	+3.29	492	+3.25

TUNGSTEN STEEL.

$T=439\text{ gr.}$		$T=1020\text{ gr.}$		$T=1810\text{ gr.}$	
H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$	H	$\frac{\delta E}{E_H} \times 10^2$
14.0	-0.01	15.1	-0.01	18.2	-0.04
19.4	-0.04	18.2	-0.03	20.5	-0.08
23.1	-0.17	22.4	-0.07	23.0	-0.07
25.4	-0.08	25.6	-0.03	38.4	+1.24
36.6	+1.61	30.2	+0.80	56.5	+1.48
68.1	+1.89	41.1	+1.34	75.7	+1.58
91.9	+2.02	68.5	+1.57	144.3	+1.61
270	+2.12	224	+1.88	230	+1.66
387	+1.99	348	+1.81	361	+1.69
486	+2.10	472	+1.78	460	+1.69

In the former results, the value of $\frac{\delta E}{E}$ depended considerably on the suspended weight; but in our recalculated results, it was only slightly affected by the weight, except in the case of

nickel in weak fields, where its initial decrease was considerably reduced.

For Swedish iron and tungsten steel, the results somewhat resemble those of the present experiment deduced from the magnetic elongation. But they are several times greater as compared with the results of the direct experiment. In nickel, the course of the curve is considerably different from that of the present experiment; its form is, however, very interesting, if we consider it in connection with that of the curve $\frac{\partial K}{\partial H}$ to H . It is here to be noticed that as regards magnetic quality, the specimen in the present experiment was very different from that used in the former experiment, so that the quantitative comparison of the two results is of little value.

§ 3. EXPERIMENTS ON THE CHANGE OF RIGIDITY BY MAGNETIZATION.

(a) Measurement of the change of rigidity by the oscillation method.

One of our methods consisted in giving torsional oscillation to the wires magnetized with different fields and calculating the coefficient of rigidity for different fields from the periods of oscillation. The wires tested were the same as those used in the above experiment for the change of elasticity. The wire was hung vertically in the field of the magnetizing coils used in the previous experiment. Its upper end was brazed to a rigid brass rod, which was clamped to the frame above. To the lower end, a similar rod was brazed, to which the oscillating weights were fixed. In order to sufficiently diminish the disturbance due to

the resistance of air, the Foucault current etc., the period of oscillation was made very long by using a weight with considerable moment of inertia. A rectangular brass bar ($42.80 \times 0.895 \times 1.946$ cm.³) was horizontally fixed to the lower end of the lower rod, at its middle point. Two equal cylindrical weights (each 657 gr.) made of lead could be fixed symmetrically on the bar at any desired distance from the middle. Besides, two equal cylindrical weights (1671 and 1640 gr.) of lead could be put on the bar with their axes coinciding with that of the rod. Suitable combinations of these different weights enabled us to adjust the periods of oscillations for different tensions to convenient values. A light mirror was fixed to the lower rod. The image of a horizontal scale placed in front of the arrangement was observed with a telescope in the usual manner.

To start the torsional oscillation of the wire, a lead tube was directed to one end of the horizontal bar. The tube going to the observer was held by his hand; the oscillation was started by blowing through the tube, while observing through the telescope. The amplitude of the oscillation could be increased or diminished at will, by blowing with suitable force on the bar in a suitable phase of its oscillation. In this way, the equality of the amplitude could easily be effected within 1 mm. of the scale. It was usually 5 cm. with a scale distance of 1.46 m., which corresponds to an amplitude of about 1° .

It was necessary to protect the oscillating system from disturbance due to air currents.

Our procedure was as follows:— The wire to be tested was first demagnetized by reversals, the zero of the scale set to the position of equilibrium; a field was applied, and then oscillation started. Care was taken to adjust the amplitude for different fields

so as to make them as equal as possible, in order that in the comparison of periods for different fields, the effects of amplitudes might be neglected. One of the observers signalled at each complete oscillations, while the other recorded the time by a mean time chronometer. According to the usual method of time-observation, 60 consecutive oscillations were availed of for the determination of its period. The first and the last 10 were signalled and recorded; we thus obtained 10 sets of time records for 50 complete oscillations. The mean of these observations gave the period of oscillation, which usually ranged from 10 to 20 seconds. Its value may be considered accurate to $\frac{1}{1000}$ of a second. These processes were repeated for a series of successively increasing fields, the demagnetization being of course effected before each experiment. After a series of observations was taken, the experiment at no field was again repeated, and we usually found the result fairly unchanged.

Since the magnetizing coil was waterjacketed, the heating-effect was inappreciable. The magnetizing current was measured both before and after each experiment, and the mean was taken. The current remained fairly constant during each experiment, except in a few cases.

Though the period of oscillation was long and the oscillating weights were moderately distant from the lower end of the coil, it was necessary to determine experimentally the retarding effect of the Foucault current, which was liable to be produced in the system vibrating in the magnetic field. For this purpose, a copper wire of the same size as the specimen was oscillated in a number of fields and the corresponding periods were determined. We found that for the periods used in our experiments, the effect was negligeably small. Logarithmic decrements for different fields

were also determined; but generally no appreciable change was observed. In some of the magnetic wires, the damping of the oscillation was found to become slightly faster as the field was increased. But, the change of the logarithmic decrement was too small to sensibly affect the period of oscillation, when referred to the equation

$$T = T_o \left(1 + \frac{z^2 T_o^2}{8\pi^2} \right)$$

where T is the actual period of oscillation, T_o that for no damping and z the logarithmic decrement. This agrees with the results* by Ignaz Klemenčič, and H. Tomlinson for iron.

The values of rigidity at no field were calculated from the period of oscillation for the bar only, whose moment of inertia was known from its dimensions.

In the oscillation method, the right order of applying the twist and the field was followed. Since the oscillation was very slow, the value of the rigidity thus determined may properly be considered to be the statical value. The results of experiments are as follows:—

* Ignaz Klemenčič, *Wien. Ber.* **78**, Nov. 7, 1878, 8.

H. Tomlinson, *Proc. Roy. Soc.* **40**, 447; *Phil. Trans.* **179**, 1, 1888.

TABLE XXV. $K_0 = 0.96 \times 10^{12}$

Nickel. Fig. 29.

 $t = 14^\circ.7$ C.

$T = 1158 \text{ gr./mm.}^2$		$T = 3410 \text{ gr./mm.}^2$		$T = 6215 \text{ gr./mm.}^2$		$T = 9075 \text{ gr./mm.}^2$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
3.9	-0.21	3.9	-0.10	4.1	-0.00	—	—
10.5	-1.61	10.2	-0.25	12.0	-0.10	11.8	-0.01
23.7	-4.21	24.1	-1.51	24.1	-0.34	24.1	-0.08
46.9	-6.80	48.2	-5.82	47.9	-1.87	47.7	-0.67
78.2	-6.80	77.8	-8.65	78.0	-5.11	77.6	-2.04
117.0	-5.92	116.2	-8.55	116.5	-9.14	123.7	-5.06
190	-3.33	189	-6.58	190	-9.22	196	-8.57
276	-0.43	297	-2.86	276	-6.93	287	-8.59
406	+2.12	390	-0.62	401	-3.21	382	-6.35

Among ferromagnetic metals tested, nickel undergoes the greatest change of rigidity and shows the most remarkable feature as regards the effect of tension. For small tensions, the rigidity at first decreases rapidly and after passing through a minimum, increases slowly with the field. In a certain field, the change is zero, beyond which there is an increase. As the tension is increased, the change becomes less for low fields, but greater for higher fields; the maximum change occurs in a higher field, and its amount increases up to a certain tension, and then slowly decreases. The point of no change shifts toward higher fields, as the tension increases.

Swedish Iron and Tungsten Steel. Figs. 30 and 31.

TABLE XXVI.

SWEDISH IRON; $K_0 = 0.756 \times 10^{12}$. $t = 14^{\circ}.6$ C.		TUNGSTEN STEEL; $K_0 = 0.608 \times 10^{12}$. $t = 14^{\circ}.0$ C.	
$T = 3113$ gr./mm. ²		$T = 3240$ gr./mm. ²	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
24.5	-0.03	24.2	-0.03
74.4	+0.15	72.1	+0.00
146.2	+0.40	162.7	+0.02
280	+0.28	—	—
385	+0.25	403	+0.12

The rigidity of Swedish iron slightly decreases in weak fields, but generally increases by magnetization. The amount of increase becomes greater and then slowly decreases with the field. The change of rigidity of tungsten steel is very small; it slightly decreases at first, and then steadily increases with the field. Both of these specimens are characterised by the smallness of the change of rigidity as well as that of elasticity. By a similar method, H. Tomlinson* found that for a moderate field, the change of rigidity of an annealed iron wire is insensibly small.

* H. Tomlinson, loc. cit.

Nickel Steels. Figs. 32, 33 and 34.

TABLE XXVII.

28.74 % Ni; $K_0=0.613 \times 10^{12}$. $t=15^{\circ}.5$.

$T=928 \text{ gr./mm.}^2$		$T=1806 \text{ gr./mm.}^2$		$T=4096 \text{ gr./mm.}^2$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
—	—	3.8	0.03	6.2	0.06
12.2	0.29	12.0	0.25	11.8	0.13
48.0	0.43	47.9	0.34	48.1	0.29
117.7	0.53	116.9	0.42	116.3	0.34
206	0.54	204	0.44	204	0.35
303	0.53	301	0.44	300	0.33
409	0.48	406	0.46	403	0.38

50.72 % Ni; $K_0=0.365 \times 10^{12}$. $t=14^{\circ}.3 \text{ C.}$

$T=1114 \text{ gr./mm.}^2$		$T=3277 \text{ gr./mm.}^2$		$T=5974 \text{ gr./mm.}^2$		$T=8725 \text{ gr./mm.}^2$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
4.0	-0.60	3.8	-0.23	3.8	-0.37	3.8	-0.22
7.9	-0.23	7.8	+0.28	7.7	-0.28	8.0	-0.59
16.4	+1.24	15.9	+1.48	15.7	+0.46	15.8	+0.51
32.9	+3.17	33.0	+3.03	32.6	+1.41	31.2	+1.05
58.0	+4.73	56.8	+4.14	56.8	+2.31	54.9	+1.75
121.0	+6.01	117.3	+5.44	117.3	+3.46	116.6	+2.58
196	+6.73	205	+6.06	202	+4.07	204	+3.24
283	+7.12	278	+6.57	288	+4.24	290	+3.42
387	+7.16	379	+6.92	386	+4.64	394	+3.60

70.32 % Ni; $K_0 = 0.640 \times 10^{12}$. $t = 16^\circ.5$ C.

$T = 1086 \text{ gr./mm.}^2$		$T = 3198 \text{ gr./mm.}^2$		$T = 5828 \text{ gr./mm.}^2$		$T = 8510 \text{ gr./mm.}^2$	
H	$\frac{\delta K}{K_H} \times 10^2$	H	$\frac{\delta K}{K_H} \times 10^2$	H	$\frac{\delta K}{K_H} \times 10^2$	H	$\frac{\delta K}{K_H} \times 10^2$
3.3	-1.18	1.9	-0.02	2.4	-0.23	2.3	-0.60
5.2	-0.86	3.3	+0.25	5.9	+0.09	6.0	-0.40
7.8	-0.24	6.2	+0.97	—	—	—	—
15.6	+1.72	12.9	+1.99	11.7	+0.64	11.3	-0.12
24.1	+3.00	—	—	24.2	+1.50	24.5	+0.44
48.0	+4.64	46.3	+4.17	47.7	+2.22	48.6	+1.00
77.6	+5.41	90.5	+4.97	78.4	+2.70	86.5	+1.44
116.2	+5.96	163.2	+5.50	167.0	+3.27	—	—
204	+6.33	238	+5.67	241	+3.49	208	+2.01
300	+6.43	316	+5.79	301	+3.55	306	+2.14
394	+6.55	401	+5.86	410	+3.64	414	+2.08

In general features, the change of rigidity is similar for the three specimens. Magnetization generally increases the rigidity; the change increases rapidly with the field and soon tends to asymptotic values. The effect of tension is invariably to diminish the change of rigidity. The last two specimens, which in weak fields, display a slight decrease of rigidity, resemble each other not only in their general behaviour, but also in the amount of their change. In 28.74 % Ni., the amount of the change is much less than that for the others. It is to be noticed that the general aspect of the change of rigidity resembles that of the change of elasticity.

(b) **Measurement of the change of rigidity by
Barus's method.**

The same specimens, on the other hand, were tested by the differential method used by Barus,* in which the wires were first

* Barus, loc. cit.

twisted and then magnetized. In our experiments, instead of the magnetic wire, a copper one was used for the compensation of the twist at no field, in order to avoid any ambiguity caused by the magnetization of the compensating wire. The specimens were cut from the previous samples into about one-third of their lengths. The copper wire was so chosen that its total twist for a given couple was nearly equal to that of the magnetic specimen to be tested. The two wires were connected in the same line by a copper rod of moderate diameter with a small mirror attached to it, and hung vertically from a torsion circle. The lower end of the specimen was also rigidly connected to another copper rod. To this rod, a rigid pin was perpendicularly fixed, the ends of which slid in the vertical grooves cut on the inside of a flat hollow cylinder at the center of the lower torsion circle. In this way, the tension applied to the pan hanging on the lower end of the lower copper rod was transmitted independently of the twist. The upper and lower ends of this connected system could therefore be twisted to any desired amount by means of the torsion circles, while the tension was constantly acting on the wire. A magnetizing coil, whose length was 30 cm. and $4\pi n=379.7$, was placed co-axially with the lower wire, which was, in our case, the specimen to be tested. The coil had a small resistance of 0.62, so that the effect of heating was negligibly small, though the water-jacketed arrangement was dispensed with. A long scale distance of 6.797 m. was used to increase the sensitiveness of the arrangement. The sensitiveness was such that a deflection of 1 scale division corresponded to a change of total twist of 15.2".

To stop the vibration of the mirror, a short brass wire was fixed horizontally to the vertical copper rod a little below the

reflecting mirror and bent downward. Just below it, a small mercury cup was placed, into which the wire dipped.

Our method of observation was as follows:—First the torsion circles were adjusted so that the magnetic field produced no deflection of the mirror. The readings of both circles for this position corresponded to those of the untwisted state of the wire. Next the lower circle was twisted by θ and then the upper circle was twisted in the opposite sense, until the mirror regained its original position for no field. Let the angle through which the upper circle was twisted be denoted by θ' ; θ' was nearly equal to θ . After demagnetization by reversals, the mirror usually turned through a small angle; but the amount of the rotation was usually so small that we could leave it out of account. Different fields were successively applied and corresponding deflections were read off. Next the twist was increased and the procedure repeated.

The experiments were made also for different tensions. Before increasing the tension, the wire was untwisted to the original state of no twist, after passing through a cyclic twist of gradually decreasing amplitude about the position of no twist. This procedure was always necessary to restore the wire to the state of no twist, since the simple untwisting usually left a residual deflection.

If the couples required to give unit twist to the two wires be τ and τ' respectively, we have

$$\tau\theta = \tau'\theta';$$

if the angular deflection of the mirror due to magnetization be $\delta\theta$, and $\delta\tau$ the increment of τ , we have

$$\tau_H = \tau + \delta\tau \quad \text{and} \quad (\tau + \delta\tau)(\theta - \delta\theta) = \tau'(\theta' + \delta\theta)$$

$$\text{or} \quad \tau_H(\theta - \delta\theta) = \tau'(\theta' + \delta\theta) \quad \text{and} \quad \delta\tau(\theta - \delta\theta) = \delta\theta(\tau' + \tau),$$

hence by division, we get

$$\frac{\partial \tau}{\tau_H} = \frac{\partial \theta(\tau + \tau')}{\tau'(\theta' + \partial \theta)} = \frac{\partial \theta \left(1 + \frac{\tau}{\tau'}\right)}{\theta' + \partial \theta},$$

or,

$$\frac{\partial K}{K_H} = \frac{\partial \theta(\theta + \theta')}{\theta(\theta' + \partial \theta)},$$

where K is the rigidity of the specimen, and ∂K its change due to magnetization. If $\frac{\partial \theta}{\theta}$ be neglected, we have

$$\frac{\partial K}{K_H} = \frac{\partial \theta}{\theta} \left(1 + \frac{\theta}{\theta'}\right).$$

If the change were greater than 1%, the first equation was used, and if it were less, the second equation was availed of.

The results of experiments are as follows:—

Nickel. Fig. 35.

TABLE XXVIII.

$\theta = 2.5^\circ$

$t = 21.0^\circ \text{C.}$

$T = 1022 \text{ gr./mm.}^2$		$T = 3096 \text{ gr./mm.}^2$		$T = 5465 \text{ gr./mm.}^2$	
H	$\frac{\partial K}{K_H} \times 10^2$	H	$\frac{\partial K}{K_H} \times 10^2$	H	$\frac{\partial K}{K_H} \times 10^2$
8.3	+ 0.83	4.9	+ 0.84	9.3	+ 0.34
13.9	— 0.24	9.7	+ 1.41	15.0	+ 0.30
23.3	— 2.37	18.7	+ 0.00	21.5	— 0.30
43.7	— 3.11	43.0	— 8.81	26.4	— 1.26
86.8	— 0.41	85.4	— 10.04	42.4	— 7.00
125.6	+ 2.45	123.4	— 6.84	85.3	— 17.33
145.8	+ 3.58	143.2	— 5.37	123.8	— 15.21
207	+ 6.39	204.4	— 1.43	174.2	— 10.45
311	+ 9.17	304	+ 2.53	305	— 2.90
441	+ 11.00	432	+ 5.13	432	+ 0.43

$$\theta = 5.0^\circ$$

$T = 1022 \text{ gr./mm.}^2$		$T = 3096 \text{ gr./mm.}^2$		$T = 5465 \text{ gr./mm.}^2$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
6.2	+ 0.68	4.0	+ 0.67	5.6	+ 0.08
11.3	— 0.08	8.8	+ 1.39	10.1	+ 0.12
19.6	— 1.54	15.3	— 0.48	15.4	— 0.31
42.8	— 2.14	26.9	— 4.87	27.1	— 3.05
86.3	— 0.00	43.3	— 7.94	42.8	— 7.87
124.2	+ 2.18	86.2	— 7.33	85.7	— 13.51
145.8	+ 3.27	143.6	— 3.84	123.8	— 11.95
208	+ 5.68	207	— 0.70	174.2	— 8.53
310	+ 8.26	309	+ 2.76	306	— 2.25
439	+ 10.06	438	+ 5.38	432	+ 0.76

In nickel, the change of rigidity and the effect of tension are very remarkable. Under small tension, the rigidity first increases slightly, then decreases rapidly as the field is increased, attains a minimum and gradually increases, till in a certain field, it recovers its initial value. As the field is further increased, the rigidity increases by magnetization. If the tension is increased, the field corresponding to the maximum decrease moves towards higher fields, and the amount of decrease is remarkably increased. Tensions here used were so adjusted as to be nearly equal to those in the oscillation method. The effect of the amplitude of twist was to diminish the change of rigidity in its absolute amount.

Comparing the above results with those of the oscillation method, we notice that in weak tensions, the curve of the change of rigidity as given by Barus's method lies considerably above the curve of the change by the oscillation method, and that in greater tensions, the contrary is the case.

Swedish Iron and Tungsten Steel. Figs. 36 and 37.

TABLE XXIX.

SWEDISH IRON.

 $T=3271 \text{ gr./mm.}^2 \quad t=20^{\circ}.0 \text{ C.}$

$\theta=2.5^{\circ}$		$\theta=5.0^{\circ}$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
4.4	0.32	3.9	0.19
10.5	1.00	10.2	1.01
20.0	1.36	16.5	1.27
42.6	1.88	25.2	1.51
75.5	2.20	42.2	1.81
123.1	2.35	75.5	2.06
174.0	2.51	171.4	2.34
306	2.56	301	2.42
434	2.67	428	2.51

TUNGSTEN STEEL.

 $T=3405 \text{ gr./mm.}^2 \quad t=20^{\circ}.1 \text{ C.}$

$\theta=4.0^{\circ}$		$\theta=8.0^{\circ}$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
13.6	0.00	12.6	0.00
21.8	0.08	18.3	0.07
27.1	0.14	29.3	0.17
46.0	0.20	44.7	0.21
81.3	0.30	76.4	0.30
134.1	0.38	123.8	0.38
172.9	0.40	172.2	0.41
304	0.45	300	0.49
429	0.51	425	0.52

Thus the rigidity of these metals always increases with the field; the change for Swedish iron is tolerably large; but, for tungsten steel, it is very small. As to the effect of amplitude of twist, it is slightly to diminish the change in Swedish iron, but is almost insensible in tungsten steel. The change of rigidity obtained by Barus's method, is several times greater than that by the oscillation method. Thus, in the case of ferromagnetic metals, relation (3) does not hold even approximately.

28.74 % Nickel Steel. Fig. 38.

TABLE XXX.

 $t = 21.^\circ 2$.

$T = 948 \text{ gr./mm.}^2$		$T = 1768 \text{ gr./mm.}^2$		$T = 4240 \text{ gr./mm.}^2$	
$\theta = 2.5^\circ$		$\theta = 3.5^\circ$		$\theta = 3.5^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
3.4	0.08	3.8	0.12	3.7	0.11
10.5	0.31	9.5	0.25	10.3	0.23
23.0	0.42	20.5	0.41	19.7	0.30
86.1	0.56	42.7	0.45	42.2	0.34
145.0	0.61	83.5	0.45	86.1	0.40
—	—	142.1	0.45	145.4	0.41
307	0.56	307	0.48	311	0.41
434	0.56	437	0.48	441	0.41
$\theta = 7.5^\circ$		$\theta = 7.5^\circ$		$\theta = 7.5^\circ$	
3.2	0.09	3.8	0.09	3.8	0.12
9.9	0.24	9.3	0.22	10.8	0.21
21.4	0.34	19.0	0.31	20.6	0.28
43.2	0.41	42.9	0.40	23.8	0.31
124.9	0.45	83.5	0.42	84.6	0.35
206	0.45	143.0	0.42	143.9	0.36
310	0.46	307	0.44	309	0.36
436	0.46	436	0.44	436	0.36

50.72 % Nickel Steel. Fig. 39.

TABLE XXXI.

 $t=19^{\circ}.0\ C.$

$T=1136\ gr./mm.^2$		$T=3445\ gr./mm.^2$		$T=6084\ gr./mm.^2$	
$\theta=2.5^{\circ}$		$\theta=2.5^{\circ}$		$\theta=2.5^{\circ}$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
3.2	0.30	3.4	0.24	3.0	0.03
7.3	1.32	8.5	1.27	7.7	0.53
14.1	2.93	14.6	2.31	14.1	1.26
22.6	4.35	22.9	3.33	22.9	2.08
35.3	5.87	35.6	4.45	35.3	2.89
49.7	6.95	49.3	5.24	49.9	3.59
69.6	7.90	69.1	6.00	69.6	4.23
94.1	8.66	93.8	6.62	94.1	4.79
132.7	9.42	133.4	7.26	132.7	5.30
202	10.06	203	7.84	203	5.90
302	10.52	303	8.23	303	6.30
430	10.83	429	8.51	429	6.57
$\theta=5.0^{\circ}$		$\theta=5.0^{\circ}$			
3.1	0.52	3.2	0.23		
7.0	1.35	7.4	1.05		
14.2	2.93	13.9	2.17		
22.3	4.27	22.7	3.28		
34.9	5.70	35.2	4.36		
49.0	6.77	49.5	5.17		
68.9	7.71	69.6	5.97		
93.8	8.51	94.1	6.60		
132.3	9.17	133.4	7.20		
202	9.87	203	7.83		
302	10.30	303	8.27		
428	10.60	430	8.54		

70.32 % Nickel Steel. Fig. 40.

TABLE XXXII.

 $t=19^{\circ}.2\ C.$

$T=1109\ gr./mm.^2$		$T=3361\ gr./mm.^2$		$T=5936\ gr./mm.^2$	
$\theta=2.75^{\circ}$		$\theta=2.65^{\circ}$		$\theta=2.55^{\circ}$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
3.8	0.06	3.0	0.26	3.2	0.07
—	—	6.7	0.97	11.1	0.97
11.1	2.20	15.5	2.33	21.1	1.72
23.2	4.44	23.5	3.16	22.9	1.92
35.8	5.70	35.7	3.92	34.7	2.41
—	—	50.3	4.48	48.9	2.92
64.1	6.99	69.2	4.95	68.9	3.32
85.7	7.77	93.8	5.35	93.6	3.64
150.2	8.19	132.1	5.69	131.9	4.00
248	8.60	202	6.03	202	4.28
342	8.69	303	6.25	303	4.54
432	8.83	430	6.34	433	4.61
$\theta=5.3^{\circ}$		$\theta=5.1^{\circ}$		$\theta=5.05^{\circ}$	
4.5	0.36	3.3	0.37	2.7	0.17
—	—	7.8	1.18	9.2	0.82
12.9	2.18	15.8	2.26	18.0	1.50
23.1	3.69	22.8	2.90	23.5	1.83
39.8	5.02	34.2	3.64	34.8	2.32
—	—	48.5	4.23	49.1	2.80
57.9	5.77	68.9	4.70	69.6	3.17
93.8	6.55	93.8	5.06	94.1	3.48
132.0	6.94	131.6	5.39	132.7	3.80
203	7.28	202	5.71	202	4.11
304	7.53	302	5.94	298	4.30
432	7.67	431	6.05	429	4.43

Thus the change of rigidity in these nickel steels is similar, in its general aspect, to that given by the oscillation method. In 50.72 % Ni. and 70.32 % Ni., however, the small initial decrease of rigidity is not observed. Increased twist diminishes the change of rigidity ; increased tension affects the change in a similar manner but in a greater degree. The change as given by Barus's method is generally greater than that by the oscillation method. The difference becomes less as the tension is increased. In 28.74 % Ni., the results by the two different methods fairly agree, and the agreement becomes closer with increased tension. Thus, also in these alloys, relation (3) is not generally satisfied, except in 28.74 % Ni. The difference, however, becomes less as the tension is increased.

Beside the above samples, a number of others including iron and nickel steels of different percentages, were tested with the purpose of studying the different behaviours of the different specimens. The samples were as follows:—

Samples	Diameter	Length
Swedish iron	1.01 mm.	20.18 cm.
23.6 % Ni.	0.71	19.63
26.64 % Ni.	1.01	20.90
24.04 % Ni.	0.96	20.30
35 % Ni.	0.95	19.70
45 % Ni.	0.95	19.58
70.32 % Ni.	1.00	20.12

All these specimens were slightly annealed by a Bunsen flame. In the case of Swedish iron and 70.32 % Ni., if we compare the following results with those obtained above, we can notice the effect of annealing on the change of rigidity. The

irreversible nickel steels were also tested after being cooled in liquid air.

To study the effect of the amplitude of twist, three different twists were usually applied, differing by about 2.5° from each other. Three or four different tensions were also applied for studying the effect of tension.

Swedish Iron. Figs. 41, 42, 43 and 44.

TABLE XXXIII.

$$T = 120 \text{ gr./mm.}^2$$

$\theta = 2.45^\circ$		$\theta = 4.8^\circ$		$\theta = 7.25^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
9.3	0.18	8.5	0.17	9.3	0.13
21.5	0.37	22.2	0.43	21.5	0.36
46.7	0.71	47.0	0.68	46.7	0.59
88.8	0.97	90.9	0.88	88.8	0.81
179.8	1.07	183.5	1.04	182.8	0.90
281	1.12	283	1.09	281	1.02
376	1.14	376	1.14	404	1.07
484	1.23	484	1.20	483	1.07

Thus the imperfect annealing did not change its general behaviour as regards the change of rigidity by magnetization. The amount of the change in the present specimen is, however, about one-half that of the change in the well annealed specimen. The change is almost independent of the tension. The amplitude of twist affects the results in a slight degree; the change increases, in general, at first slightly and then decreases with the twist.

The hysteresis for a cyclic change of the field is given in Fig.

44. The curve was obtained after several cyclic changes of the field.

23.6 %, 26.64 % and 24.04 % Nickel Steels.

Figs. 45, 46, 47, 48, 49, 50 and 51.

TABLE XXXIV.

23.6 % Ni; $T=242 \text{ gr./mm.}^2$

$\theta=2.4^\circ$		$\theta=4.65^\circ$		$\theta=6.9^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
6.7	+0.08	5.9	-0.01	4.4	0.00
24	-0.07	23	-0.02	23	0.00
62	-0.43	88	-0.24	88	-0.12
198	-0.14	197	-0.18	197	-0.12
340	-0.00	335	+0.16	333	-0.00
507	+0.14	501	+0.16	497	+0.09

24.04 % Ni; $T=133 \text{ gr./mm.}^2$

$\theta=2.1^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$
60	-0.02
107	-0.15
201	-0.08
338	0.00
487	0.00

26.64 % Ni; $T=120 \text{ gr./mm.}^2$

$\theta=2.35^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$
22	0.00
107	-0.04
209	-0.00
350	+0.02
507	+0.04

The change of rigidity in these irreversible nickel steels is inappreciably small at ordinary temperatures. After cooling them in liquid air, a small change is observed, as shown in the above

table. The change is common for all these specimens; the rigidity first decreases, attains a minimum, and then gradually recovers its initial value, as the field is increased. In still higher fields, a slight increase is observed, which increases with the field.

The fact that the change of rigidity becomes appreciable, only when the specimens are once dipped in liquid air, is to be expected from its magnetic property as regards the cooling in liquid air.*

35 % Nickel Steel. Figs. 52, 53, 54, 55 and 56.

TABLE XXXV.

$$T=135 \text{ gr./mm.}^2$$

$\theta=3.25^\circ$		$\theta=6.3^\circ$		$\theta=9.35^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
7.4	1.27	8.0	1.06	6.7	0.61
21.5	3.13	21.5	2.63	21.5	2.07
58.1	4.93	57.9	4.36	57.9	3.71
101.1	5.71	101.1	5.05	100.3	4.41
184.6	6.23	185.0	5.60	184.0	4.92
291	6.49	291	5.84	286	5.20
389	6.55	387	5.91	387	5.29
508	6.66	502	6.01	497	5.37

* K. Honda and S. Shimizu, Jour. Sci. Coll. Vol. XX, Art. 6.

$T=1594 \text{ gr./mm.}^2$		$T=3060 \text{ gr./mm.}^2$		$T=4490 \text{ gr./mm.}^2$	
$\theta=3.15^\circ$		$\theta=3.25^\circ$		$\theta=2.85^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
7.1	0.63	6.5	0.31	8.5	0.33
21.5	2.08	21.5	1.65	22.2	1.01
57.8	3.57	57.8	2.89	59.2	1.95
100.2	3.96	100.1	3.43	103.3	2.30
182.8	4.56	183.5	3.90	190.9	2.65
286	4.80	285	4.02	300	2.91
385	4.89	383	4.17	408	2.94
498	5.09	492	4.23	492	2.94

The rigidity considerably increases with the field and tends to an asymptotic value. The effect of tension is regularly to decrease the change of rigidity. The amplitude of twist affects the change similarly as in Swedish iron. The hysteresis-curve also resembles that of the same metal, but is smaller in its area.

45 % Nickel Steel. Figs. 57, 58, 59, 60 and 61.

TABLE XXXVI.

$T=362 \text{ gr./mm.}^2$

$\theta=3.25^\circ$		$\theta=6.35^\circ$		$\theta=12.4^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
8.0	-0.49	8.0	-0.42	7.7	-0.23
16.0	-0.41	14.1	-0.33	14.5	-0.22
32.3	+0.32	30.5	+0.23	30.4	+0.15
41.2	+0.63	41.4	+0.61	41.4	+0.52
61.1	+1.40	61.9	+1.29	62.0	+1.08
95.3	+2.21	91.7	+2.25	97.0	+1.91
166.8	+3.10	168.3	+3.24	168.9	+2.95
273	+3.70	273	+3.96	276	+3.65
406	+4.07	406	+4.38	406	+4.05
486	+4.21	486	+4.46	485	+4.14

$T=1390 \text{ gr./mm.}^2$		$T=2623 \text{ gr./mm.}^2$		$T=3895 \text{ gr./mm.}^2$	
$\theta=3.3^\circ$		$\theta=3.1^\circ$		$\theta=3.15^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
4.6	-0.10	4.1	-0.03	4.0	+0.00
8.8	-0.24	8.4	-0.12	9.0	+0.07
14.8	-0.10	—	—	17.7	+0.49
22.3	+0.12	18.4	+0.25	29.5	+1.02
32.4	+0.60	31.1	+0.84	42.6	+1.61
41.4	+1.03	42.8	+1.38	63.4	+2.33
96.0	+2.57	96.7	+2.81	94.2	+2.90
168.0	+3.41	168.7	+3.60	164.5	+3.76
274	+4.01	271	+4.28	269	+4.31
405	+4.17	365	+4.40	391	+4.68
485	+4.29	485	+4.68	474	+4.76

In general features, the change of rigidity is similar to that of the former alloy, but the rate of increase is less for the present alloy than for the former. Under slight tension, we observe, in the alloy, a slight decrease of rigidity in very weak fields. Such an initial decrease is not observable in the former alloy. This decrease of rigidity, however, diminishes with increasing tension, vanishing with a tension of 3895 gr./mm.²

One of the two hysteresis-curves (Fig. 60) refers to the first cycle, while the other (Fig. 61) to a cycle after several cyclic changes of field. The form of the curve closely resembles the inverted form of the hysteresis curve of the magnetic change of length in iron, as discovered by Professor Nagaoka.

70.32 % Nickel Steel. Figs. 62, 63, 64, 65 and 66.

TABLE XXXVII.

$$T = 122 \text{ gr./mm.}^2$$

$\theta = 2.95^\circ$		$\theta = 6.35^\circ$		$\theta = 9.4^\circ$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
2.6	-0.06	1.9	-0.01	2.2	-0.03
6.3	-0.58	6.7	-0.31	6.3	-0.12
21.6	+0.74	21.1	+0.77	21.1	+0.71
58.5	+2.49	55.7	+2.35	55.7	+2.05
96.5	+3.17	98.0	+3.08	98.0	+2.70
178.0	+3.77	178.3	+3.53	179.4	+3.19
280	+3.95	280	+3.82	280	+3.39
410	+4.08	377	+3.87	378	+3.47
491	+4.10	491	+3.96	492	+3.54

$$T = 1440 \text{ gr./mm.}^2$$

$$T = 2760 \text{ gr./mm.}^2$$

$$\theta = 6.35^\circ$$

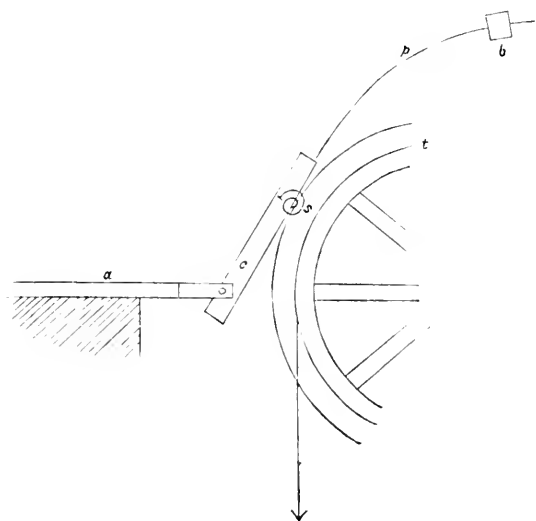
$$\theta = 6.25^\circ$$

H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
2.6	+0.13	3.7	+0.32
6.5	+0.33	6.8	+0.63
21.1	+1.43	21.5	+1.57
55.9	+2.77	56.6	+2.66
98.0	+3.37	99.2	+3.14
179.8	+3.82	181.0	+3.57
279	+4.02	285	+3.82
377	+4.12	387	+3.88
488	+4.22	499	+3.89

In general behaviour, the change of rigidity and its hysteresis resemble those of 45% Ni., except that the amount of the change is a little less than that for this alloy. Comparing the above results with those for well annealed nickel steel of the same percentage, we observe that the effect of annealing remarkably increases the change of rigidity.

(a) **Measurement of the change of rigidity by ordinary method.**

In a paper by Messrs S. Shimizu, S. Kusakabe and one of us,* the change of rigidity of ferromagnetic bars is given, having been determined by first applying the torsion and then the magnetic field. To investigate whether the results are the same or not, if the order of applying the torsion and the field, is reversed, the same arrangement used in the experiment above cited was availed of. The essential parts of the arrangement remained unchanged, except for the mirror system. The rotating cylinder,



to which the mirror was fixed, was horizontally supported by means of two very weak spiral springs (*ss*) attached to the sides of a carriage (*c*) similar to that used in our measurement of the change of elasticity. To the carriage, was rigidly fixed a horizontal axis, the conical ends

* J. K. Honda, S. Shimizu and S. Kusakabe, *loc. cit.*

of which fitted to agate cups on the arms of a Y-shaped bar (*a*). This bar could be adjusted to any desired position, such that the axis of the mirror would be pressed by the plane side of the carriage perpendicularly on a point of the circumference of the torsion wheel (*t*) rigidly fixed to the specimen. To adjust the pressure properly, a sliding weight (*b*) was put on a pin (*p*) protruding from the carriage.

Two vertical scales 30 cm. long were erected at a horizontal distance of 6.45 m. in front of the mirror in the same vertical line; one at the same height as the mirror, and the other about one meter above it. The image of the scales was observed with a telescope at the same height as the mirror. An initial couple was applied and the mirror was so adjusted that the image of the lower scale was observable with the telescope. A suitable weight was then chosen for giving an additional couple, which twisted the rod to such an extent that by the consequent rotation of the mirror, the image of the upper scale just appeared in the field of the telescope. This weight was 500 gr. The readings of the two scales corresponding to the removal and to the addition of the additional weight, were taken. When properly adjusted, their difference was fairly constant for repeated observations; the mean of several observations was always taken as the deflection due to the weight. Next, a field was applied and the procedure repeated; in this way, we obtained the values of deflections corresponding to the different fields, the demagnetization being, of course, carefully made before each experiment. The difference of the deflections in a certain field and in no field gives the change of rigidity.

The sensitiveness of the present arrangement was such that a deflection of 1 mm. of the scale reading corresponded to a twist

of $7.64'' \times 10^{-3}$ per cm. of the specimen. The specimens tested in the present experiment were those used in the previous experiment above quoted, and had the following dimensions:

Metals	Diameter	Length	Rigidity
Soft iron	0.986 cm.	20.43 cm.	7.92×10^{11}
Nickel	1.115	21.42	7.41×10^{11}

On the other hand, the determination of the change of rigidity by the ordinary method of first applying the couple and then the magnetizing field was always made, and the results obtained by the two different methods were compared. The magnetizing coil was the same as that used in the last experiment, so that the heating effect due to the magnetizing current was negligibly small.

In using the present arrangement, all necessary precautions were taken, which were referred to in the paper above quoted. The results are given in the following:—

Nickel. Figs. 67 and 68.

TABLE XXXVIII.

$N=7.00 \times 10^6$ $\theta=12.83''$		$N=14.09 \times 10^6$ $\theta=25.83''$		$N=21.27 \times 10^6$ $\theta=38.98''$	
H	$\frac{\delta K'}{K_H} \times 10^2$	H	$\frac{\delta K'}{K_H} \times 10^2$	H	$\frac{\delta K'}{K_H} \times 10^2$
6.3	+0.05	6.3	+0.07	5.6	+0.05
14.5	+0.12	13.5	+0.12	13.4	+0.11
20.5	-0.02	20.5	-0.01	22.0	-0.07
28.4	-0.34	26.7	-0.31	26.1	-0.24
34.9	-0.65	35.0	-0.68	33.8	-0.60
56.0	-1.37	55.7	-1.37	55.7	-1.24
82.8	-1.35	83.5	-1.33	81.0	-1.20
114.0	-0.60	115.8	-0.59	114.0	-0.50
164.8	+1.15	167.0	+1.16	164.8	+1.14
236	+3.40	238	+3.39	236	+3.22
288	+4.59	292	+4.61	289	+4.34
359	+5.81	365	+5.87	362	+5.57
407	+6.38	412	+6.48	410	+6.17
519	+7.39	523	+7.53	518	+7.21

$$J.V = \pm 3.50 \times 10^6, \quad t = 16^\circ.7 \text{ C.}$$

$N = 7.00 \times 10^6$ $\theta = 12.83''$		$N = 14.09 \times 10^6$ $\theta = 25.83''$	
H	$\frac{\partial K}{\partial H} \times 10^2$	H	$\frac{\partial K}{\partial H} \times 10^2$
—	—	6.8	-0.08
15.1	-0.19	15.4	-0.31
22.2	-0.55	22.2	-0.57
48.2	-1.65	48.5	-1.60
82.4	-2.35	82.4	-2.29
127.1	-2.56	127.5	-2.38
192.5	-1.94	193.2	-1.64
288	-0.67	286	-0.34
398	+0.59	386	+0.59
508	+1.37	495	+1.54

In the above tables, N is the moment of force applied in C.G.S. units, and θ the corresponding twist of the specimen as calculated from the modulus of rigidity. The change of rigidity obtained by our direct method is denoted by $\frac{\partial K}{\partial H}$, while that obtained by the indirect method, by $\frac{\partial K'}{\partial H}$. The values of $\frac{\partial K'}{\partial H}$ fairly coincide with those obtained by the previous experiment; but it is to be noticed that the field here given is not the effective one, but the external field applied. The difference between $\frac{\partial K}{\partial H}$ and $\frac{\partial K'}{\partial H}$ is remarkable; its amount is of the same order of magnitude as the change itself. The increase of the angle of twist slightly affects the change of rigidity, always diminishing it in absolute amount. The general feature of $\frac{\partial K}{\partial H}$ is quite similar to that for nickel wire with weak tension, as obtained by the oscillation method.

It is curious to observe that the residual twist is always positive and uniformly increases with the field, as shown in Fig. 68.

It may be noticed that the course of the curve of $\frac{\partial K'}{\partial H}$ close-

ly resembles that of $\frac{\partial E}{E}$ as given by the flexure method. In both cases, the right order of applying the stress and the field is inverted.

Soft Iron. Figs. 69 and 70.

TABLE XXXIX.

$t=19^{\circ}.0\ C.$

$N=7.00 \times 10^6$ $\theta=19.65''$		$N=14.09 \times 10^6$ $\theta=39.56''$		$N=21.27 \times 10^6$ $\theta=59.70''$	
H	$\frac{\partial K'}{K_H} \times 10^2$	H	$\frac{\partial K'}{K_H} \times 10^2$	H	$\frac{\partial K'}{K_H} \times 10^2$
7.3	0.01	8.4	0.02	9.3	0.01
22.0	0.07	22.0	0.07	22.0	0.06
40.0	0.11	39.6	0.14	39.6	0.12
73.3	0.23	73.3	0.27	72.6	0.25
111.3	0.63	111.0	0.68	110.6	0.65
160.5	0.95	160.5	1.03	160.5	1.02
252	1.34	252	1.42	252	1.43
322	1.51	315	1.58	315	1.60
396	1.66	395	1.73	396	1.75
511	1.79	508	1.87	509	1.87

Since the time of the previous experiment, the specimen had been once annealed at a temperature of about $1100^{\circ}\ C.$ so that the change of rigidity $\frac{\partial K'}{K_H}$ was somewhat increased in the present experiment. The effect of the amplitude of twist on the change of rigidity is very small; the increase of the twist slightly augments the change of rigidity up to the range of the twist used. The residual twist is always positive as in the case of nickel. $\frac{\partial K}{K_H}$ is always inappreciable in the present arrangement; if it exist at all, it can not be greater than 0.05 %, for the maximum field used.

Thus, in nickel and iron rods, $\frac{\partial K'}{K_H}$ is always far greater than

$\frac{\partial K}{K_H}$, so that relation (3) can not be satisfied even approximately.

In concluding the descriptions of the results of our experiments, the following remarks may be added. Since we measured the changes of elasticity and of rigidity for the same wires of ferromagnetic metals and alloys, it will be now interesting to calculate the change of Poisson ratio by magnetization. Since the change of elastic constants is considerably affected by tension, it is necessary to calculate the change of the ratio from the changes of elasticity and rigidity for the same tension.

If σ be the Poisson ratio, we have

$$\frac{\partial \sigma}{\sigma} = \frac{\frac{E}{K}}{\frac{E}{K} - 2} \left(\frac{\partial E}{E} - \frac{\partial K}{K} \right).$$

The value of $\frac{E}{K}$ used in the calculation of the following table is that for no field; and the values of $\frac{\partial E}{E}$ and $\frac{\partial K}{K}$ are those obtained by the tension effect of the magnetic elongation and by the Barus's method respectively, for in these two sets of experiments, the stress was first applied and then the magnetizing field.

TABLE XL.

Specimen.	Nickel.	Swedish iron.	Tungsten steel.	28.74% Ni.	50.72% Ni.	70.32% Ni.
Tension.	3020 gr.	3270 gr.	3320 gr.	1770 gr.	3350 gr.	3280 gr.
H	$\frac{\partial \sigma}{\sigma} \times 10^2$	$\frac{\partial \sigma}{\sigma} \times 10^2$	$\frac{\partial \sigma}{\sigma} \times 10^2$	$\frac{\partial \sigma}{\sigma} \times 10^2$	$\frac{\partial \sigma}{\sigma} \times 10^2$	$\frac{\partial \sigma}{\sigma} \times 10^2$
10		— 2.2			— 0.3	— 1.6
20		— 3.8		— 1.0		
30	— 6.1		0.0		— 1.9	
100	+ 37	— 7.4	0.0	— 1.3	— 8.3	— 14.5
150	+ 50					
200	+ 23	— 9.0	0.1	— 1.3	— 10.1	— 13.5
250	+ 7					
300			0.3	— 1.1		— 13.8
350		— 10.2			— 11.1	

From the above table, it will be seen that the Poisson ratio is generally diminished by magnetization. In nickel, it is very large amounting to even 50 per cent; but in tungsten steel, it is almost zero, indicating a tendency to increase. The change of the Poisson ratio also considerably varies with tension, and the above table shows only an example of the change.

§ 4. CONCLUDING REMARKS.

The results obtained in the present investigation may be summarised as follows:—

(i) In Swedish iron and tungsten steel (Figs. 71 and 72), the change of elastic constants is generally positive, but its amount is extremely small, less than 0.5%. The change by the indirect method is several times greater than that by the direct method. It is interesting to notice that the change of elasticity and that of rigidity almost coincide with each other, not only in their general aspects, but also in their quantitative relations.

(ii) In nickel (Fig. 73), the change of elastic constants is remarkably large, amounting to about 15% in the change of elasticity and 7% in the case of rigidity. The elastic constants first decrease and then increase, as the field becomes greater. The elastic constants by the indirect method are numerically greater than those by the direct method.

(iii) In 28.74% Ni. (Fig. 74), magnetization increases the elastic constants by a small amount. The changes given by the two different methods nearly coincide with each other for a moderate tension. In 50.72 % Ni. and 70.32 % Ni. (Figs. 75 and 76), the increase of the elastic constants is remarkably large, approaching in amount the change of rigidity in nickel. Except with a

very weak tension, the change by the indirect method is greater than that by the direct; but this difference becomes less as the tension is increased. With a tension of 3 or 4 kg. per square millimeter, it nearly vanishes.

(iv) In Fig. 77, curves showing the relation between the change of rigidity (by indirect method) and the percentage content of nickel in nickel steels are given. These curves correspond to the change of rigidity in a slightly annealed state. They show a marked maximum at about 50% Ni., and a minimum at about 24.40 % Ni.

From the results above given, it is evident that there are some cases in which, relation (3) given in the earlier part of this paper, does not hold even approximately, so that equation (1) can not be freely used in any quantitative discussion.

There are many analogous cases in the problem of magnetostriction. As will be seen from our subsequent paper to be published presently, the change of magnetization by stretching a magnetized wire does not agree with the change deduced from the results obtained by magnetizing the wire in the unstrained as well as the stretched state. Similar phenomena are also observable in the change of magnetism caused by the twist. Next, we may cite the case of the Wiedemann effect. It is well known that in iron and nickel, the twist produced by magnetizing the wire traversed by an electric current is generally greater than the twist caused by passing the current through the magnetized wire. The difference is remarkable; in some cases,* the former is several times greater than the latter. In nickel steels,† the difference is, however, very small. Again, take the case of magnetizing a

*) and †) K. Honda and S. Shimizu, Jour. Sc. Coll., **16**, Art. 14.

wire traversed by an electric current.* The change of magnetization by the longitudinal current is considerably greater, in the case of magnetizing the wire traversed by the current, than in the case of passing the current through the magnetized wire. All these phenomena may perhaps arise from the hysteresis effect of magnetization; i.e. the final states attained by a magnetic substance differ according to the order of applying the field and the stress, or the field and the longitudinal current.

In conclusion, it may be remarked that, since the change of the elastic constants by magnetization is not so small as is generally believed, in any theory of magnetostriction aiming at the quantitative agreement between the theory and the experiment, these changes must necessarily be taken into account. In addition to this, an equality such as

$$\frac{\partial^2 Q}{\partial x \partial y} = \frac{\partial^2 Q}{\partial y \partial x},$$

in which Q is a quantity which depends upon two apparently independent variables x and y , can not be used without experimental verification. These facts make the development of the theory very difficult.

In passing, the following remarks may be added. If we consider, in the above equation, Q as the length of a specimen, x the temperature and y the magnetic force, we have

$$\frac{\partial}{\partial H} \left(\frac{\partial l}{\partial t} \right) = \frac{\partial}{\partial t} \left(\frac{\partial l}{\partial H} \right),$$

provided l is independent of the order of applying the field and the temperature. Integrating, we get

$$\left(\frac{\partial l}{\partial t} \right)_H - \left(\frac{\partial l}{\partial t} \right)_0 = \frac{\partial (l_H - l_0)}{\partial t}.$$

* J. K. Honda, *Ibid.* **11**, p. 284, 1899.

If α be the coefficient of thermal expansion,

$$\alpha_H - \alpha_0 = \delta\alpha = \frac{\partial(l_H - l_0)}{l_0 \partial t}.$$

Thus the change of the coefficient of thermal expansion by magnetization is equal to the temperature coefficient of the magnetic elongation. As the latter coefficient is known from the experiment* by Mr. S. Shimizu and one of us, the values of $\delta\alpha$ are calculated and graphically drawn in Figs. 78, 79, 80, 81 and 82.

By referring to the figures, we see that the change of the coefficients of thermal expansion by magnetization depends considerably upon temperature. Ordinates of the curves represent the change of the mean coefficient of expansion between two temperatures belonging to each curve.

The change of the mean coefficient of expansion in nickel (Fig. 78) between the ordinary and liquid air temperatures first decreases, attains a minimum, and then gradually increases, as the field becomes greater, till it is greater than its initial value. At a temperature higher than the ordinary, the change of the coefficient of expansion steadily increases, soon approaching an asymptotic value. In a given field, its value increases with temperature, and after passing through a maximum, slightly decreases. The maximum amount of the change is of the order of 1% of the coefficient itself.

In soft iron and tungsten steel (Figs. 79 and 80), the change of expansion is very small. Up to a moderate temperature, the coefficient of expansion increases steadily with the field, except in weak fields, in which a small decrease is observed. At higher temperatures, the change becomes negative for all fields. In iron, a maximum decrease is observed.

*) K. Honda and S. Shimizu, Jour. Sc. Coll., XX, Art. 10, 1903.

In cast cobalt (Fig. 81), the change of the coefficient of expansion at low temperature increases with the field, reaches a maximum, and then decreases. As the temperature becomes higher, the amount of the maximum gradually lessens; the position of the maximum shifts towards lower fields and the curve at last cuts the zero line. At a sufficiently high temperature, the change of expansion is always negative.

The change of the coefficient of expansion in annealed cobalt (Fig. 82) is rather abnormal, and its maximum amount is considerably large, being about 2% of the coefficient itself. The change of the mean coefficient of expansion between the ordinary and liquid air temperatures steadily decreases with the field, though its amount is small. As the temperature rises, the amount of the diminution increases rapidly and then decreases. Here the course of the curve shows a minimum decrease of the change. As the temperature is further increased, a considerable amount of increase is observed, which steadily increases with field. It attains a maximum and again decreases, till it changes its sign.

The values of $\delta\alpha$ thus obtained may possibly differ from the values obtained by heating the specimens in a constant magnetic field. They are the changes of α by magnetization, when the temperature is first raised and then the field applied. However, any experiment for the determination of the change of α , in which the thermal expansion is directly observed in magnetic field, must be welcomed, as affording a counterpart for the analogous comparison.

Again, if we put, in the last equation, the tension T per unit area for H , we get

$$\left(\frac{\partial l}{\partial t}\right)_T - \left(\frac{\partial l}{\partial t}\right)_0 = \frac{\partial(l_T - l_0)}{\partial t},$$

or
$$\alpha_T - \alpha_0 = \delta\alpha = \frac{\partial(l_T - l_0)}{l_0 \partial t};$$

but since

$$\frac{l_T - l_0}{l_0} = \frac{T}{E},$$

we have finally

$$\frac{\delta\alpha}{T} = \frac{\partial \frac{1}{E}}{\partial t} = -\frac{1}{E^2} \frac{\partial E}{\partial t}.$$

Thus the effect of tension upon the coefficient of thermal expansion can be found from the temperature coefficient of the modulus of elasticity. The relation was first obtained by Dahlander,* and verified by him to agree well with the experiment. In problems which do not relate to magnetism, the hysteresis effect is generally very small, so that the agreement might have been expected.

*) Dahlander, Pogg. Ann. **115**, p. 147, 1872.

Fig. 1. Pure Nickel



Fig. 3. Commercial Nickel



Fig. 4. Purified Nickel



Fig. 2. Pure Nickel

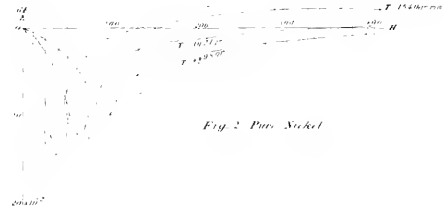


Fig. 5. Commercial Nickel

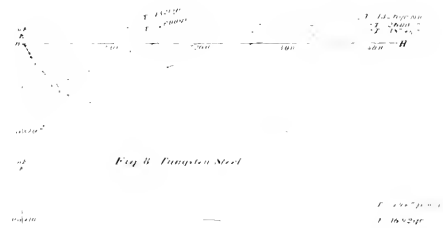


Fig. 6. Purified Nickel



Fig. 7. 2.5% V

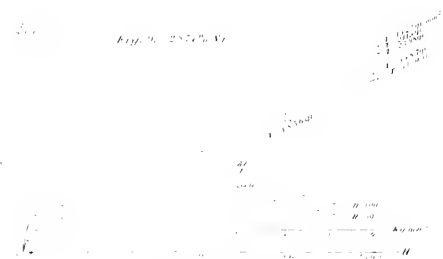


Fig. 8. Nickel-Iron

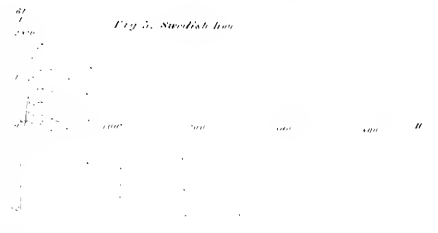


Fig. 9. Nickel-Iron

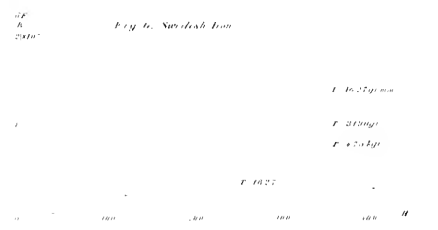


Fig. 10. 2.5% V

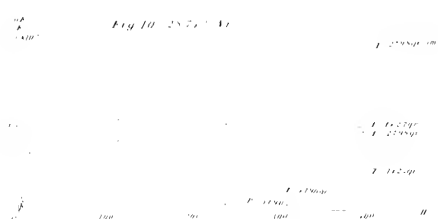




Fig. 11. 50.72° N.

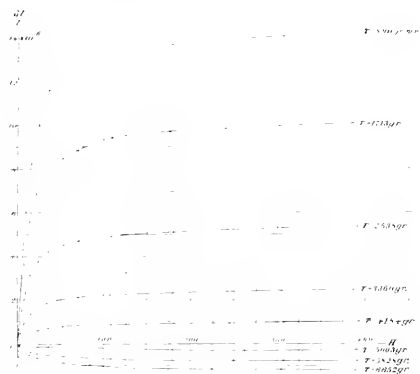


Fig. 12. 50.72° N.



Fig. 13. 70.32° N.



Fig. 14. 70.32° N.

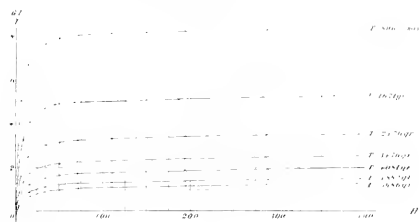


Fig. 15.

50.72° N.



Fig. 26. Soft Iron

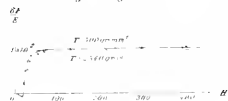


Fig. 27. Tempered Steel.

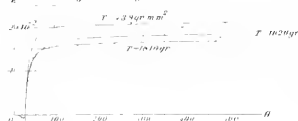


Fig. 28. Nickel.

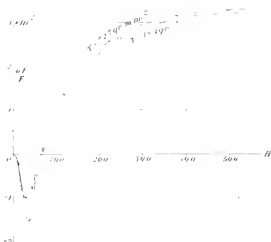


Fig. 29. Nickel

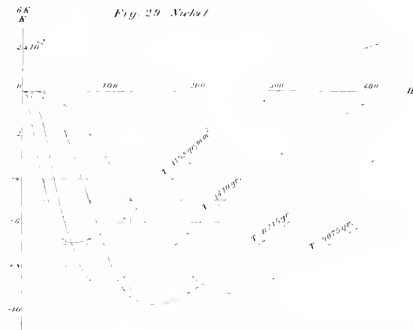


Fig. 35. Pure Nickel



Fig. 32. 28.7% Ni.

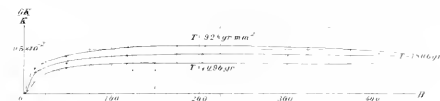


Fig. 33. 50.72% Ni.

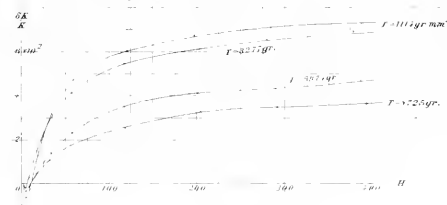


Fig. 34. 70.32% Ni.

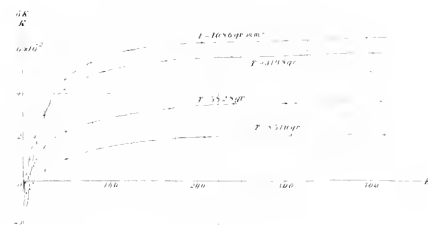


Fig. 30. Swedish Iron



Fig. 31. Tempered Steel

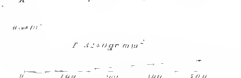


Fig. 36. Swedish Iron

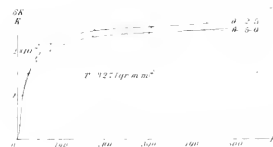


Fig. 37. Tempered Steel



Fig. 38. 23.74% Ni.



Fig. 39. 30.72% Ni.

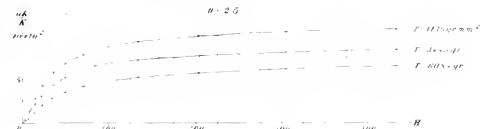


Fig. 40. 50.32% Ni.

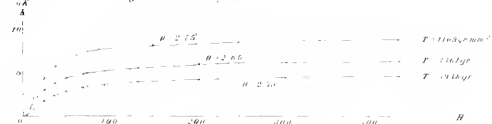


Fig. 41. Swedish Iron.



Fig. 42. Swedish Iron.

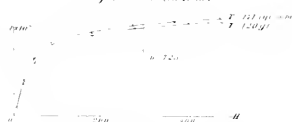


Fig. 43.



Fig. 44.

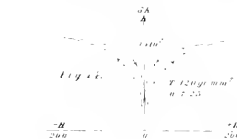


Fig. 45. 2.86% Nickel Steel.

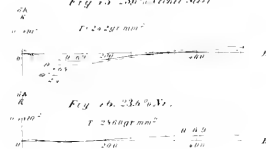


Fig. 46. 2.34% Ni.



Fig. 47. 2.40% Ni.



Fig. 48. 2.40% Ni.

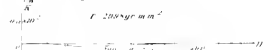


Fig. 49. 2.66% Ni.



Fig. 50. 26.6% Ni.



Fig. 51. 26.6% Ni.

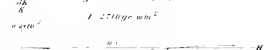


Fig. 52. 3.5% Ni.

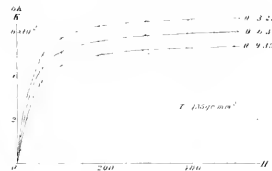


Fig. 53. 3.5% Ni.

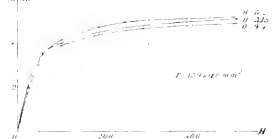


Fig. 54. 3.5% Ni.



Fig. 55. 3.5% Ni.

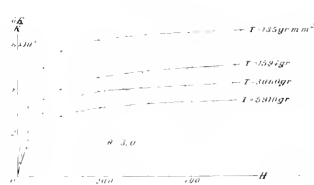




Fig. 57. 43% V_2O_5 .

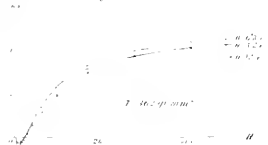


Fig. 62. 50.32% V_2O_5 .

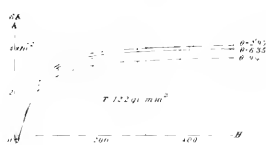


Fig. 63. 50.32% V_2O_5 .



Fig. 58. 45% V_2O_5 .



Fig. 64. 50.32% V_2O_5 .



Fig. 65. 50.32% V_2O_5 .

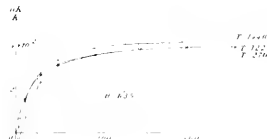


Fig. 59. 45% V_2O_5 .



Fig. 66. 50.32% V_2O_5 .



Fig. 67. Nickel.

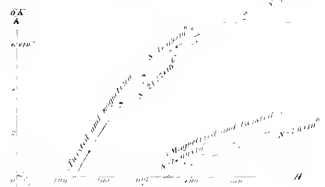


Fig. 60. 45% V_2O_5 .

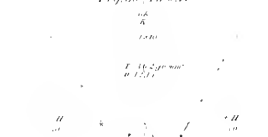


Fig. 61. 45% V_2O_5 .

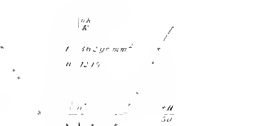


Fig. 68. Nickel.

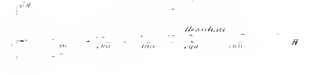




Fig. 69 Iron.

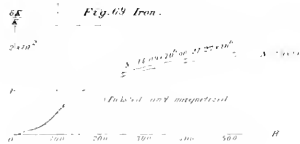


Fig. 70. Iron



Fig. 77 Nickel Steel

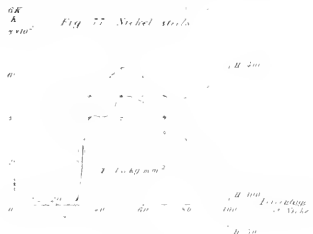


Fig. 78 2% Zn Ni



Fig. 79 50% Zn Ni

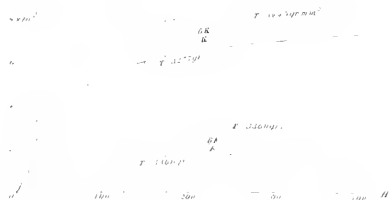


Fig. 71 Swedish Iron

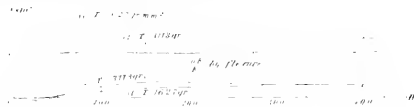


Fig. 72. Tomplate Steel

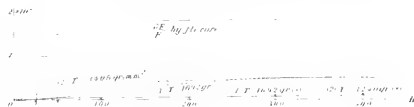


Fig. 73 Nickel

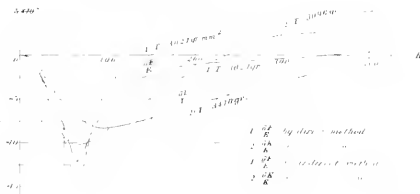


Fig. 76. 70% Zn Ni

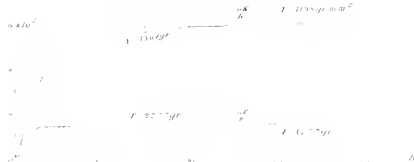


Fig. 78. Nickel.

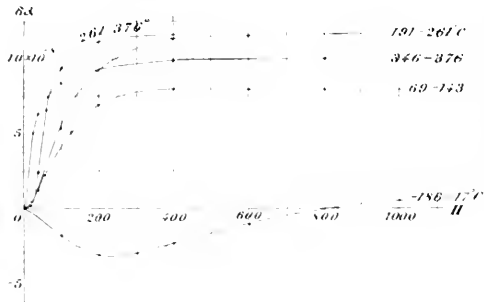


Fig. 79. Soft Iron.

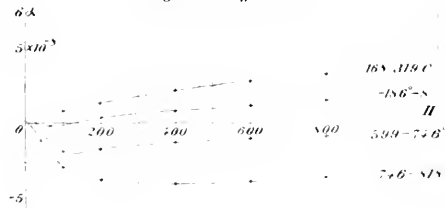


Fig. 80. Tungsten Steel.

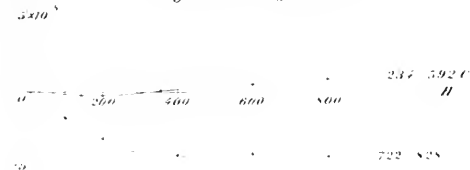


Fig. 81. Cast Cobalt.

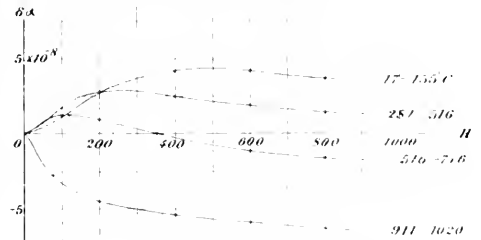
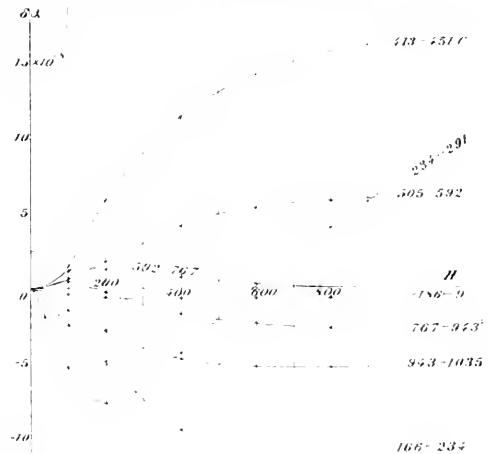


Fig. 82. Annealed Cobalt.



A Contribution to the Genus *Fusulina*, with
Notes on a *Fusulina*-Limestone
from Korea.

By

H. YABE, *Rigakushi*.

Lecturer in Geology, Sci. Coll., Imperial University of Tokyo.

With 3 plates.

The recent advance in our knowledge of the Permocarboniferous Foraminifera is largely due to the works of Prof. E. SCHELLWIEN. He studied, among other forms, those in the Carnic Alps, found the long accepted separation of the genera, *Fusulina* and *Schwagerina*, to be of only a subgeneric value, and accordingly united them under the one genus *Fusulina*, which he proposed to divide into three subgenera. To me, however, it seems more natural to subdivide it into four.

In the following descriptions of these four subgenera, I propose the use of the designations, primary-, auxiliary- and transverse septa. By primary septa, I mean those longitudinal partitions marked on the surface as deep sutures,¹⁾ and commonly called 'septa.' The auxiliary septa are those parallel to the former, but showing no suture on the outside; for they are mere stalaetic

1) The origin of the suture on the surface is evident from the explanation of SCHELLWIEN on the formation of the septa.

outgrowths of the wall; they are usually shorter, and always without a median lamella,¹⁾ which is invariably present in the primary septa. The transverse septa (the 'Nebensepten' of C. SCHWAGER) are those at right angles to the other two, extending from the roof of a volution to its floor, when completely developed. When only the basal portion of the transverse septa is developed, they appear as spiral ridges, and form what are generally called the basal skeleton ('Basalskelet'). Although all the septa, like the wall itself, are often perforate throughout their entire length, yet it frequently happens that they are imperforate in their lower portion which then appears as a quite dense calcareous mass. The basal skeleton is also never perforated, the pores being evidently not physiologically necessary.²⁾

Synopsis of the Four Subgenera.

1. FUSULINA s. s. Type: *F. cylindrica* FISCHER.

Shell fusiform or cylindrical, sometimes ellipsoidal, rarely acicular. Only the primary septa developed; these are much folded, especially near the umbilical ends.

2. SCHWAGERINA. Type: *S. princeps* EHRENBURG.
(cfr. Pl. II., fig. 1).

Shell spherical in the typical species, fusiform in those approaching *Fusulina* s. s. With only the primary septa, which are slightly or not at all folded, except near the umbilical ends.

1) The term may be inappropriate; but I mean by it a boundary line between two successive walls, which sometimes runs into the middle of the septa. See the remarks by SCHELLWIEN on the structure of the septa.

2) I agree with SCHELLWIEN in the view that the greater transparency of the wall and of the upper part of the septa is due to the intercalation of commonly transparent calcite, infiltrated in the pores; otherwise we have no reason to maintain the greater turbidity of the dense calcareous matter in the basal portion of the septa.

3. DOLIOLINA. Type: *T. lepida* SCHWAGER (Pl. II., figs. 2, 3).

Shell cylindrical in the typical species, but spherical in those approaching *Schwagerina*. Septa of two kinds; primary septa being straight and basal skeletons more or less developed.

4. NEOSCHWAGERINA. n. subg. Type: *N. craticulifera* SCHWAGER (Pl. I., figs. 3, 4).

Shell fusiform to spherical. Septa of three kinds: transverse septa numerous, and 1 to 4 auxiliary septa are found between each pair of primary septa.¹⁾

The above lines are with but slight modification,²⁾ an almost complete recapitulation of the passages in my former paper "On a *Fusulina*-limestone with *Helicoprion* in Japan." Since then two important papers treating this group of Foraminifera have been published, one by Prof. W. VOLZ and the other by Dr. G. H. Girty.

In a recent work on the geology of Sumatra,³⁾ VOLZ described a Carboniferous Foraminifera of the family Fusulinidae under the new name of *Sumatrina Annae*. This greatly interested me, as I had once found an unquestionably identical form in limestones from the province Bitchū in Japan, and from Ta-gai-tung, En-ngan-hsien, prov. Yun-nan, in China, and had taken it to be an undescribed species belonging to my *Neoschwagerina*. The reason why I describe the subgenus as sometimes fusiform is because I believe the Foraminifera is surely a form which should be included in it.

1) C. SCHWAGER, one of the most excellent observers of the fossils of this group the world ever seen, seems to have already been disposed by a similar consideration to separate *S. craticulifera* from the other allies. (Carbon. Foram. aus China u. Japan. P. 142.)

2) I here substitute 'auxiliary septa' for my older term 'secondary septa.'

3) W. VOLZ: Zur Geologie von Sumatra. Geol. u. Palæont. Abhandl.

VOLZ defines his genus *Sumatrina* as follows: "Spindelförmige Fusuliniden mit einem aus 2-4 längs- und querreifen bestehenden Dachskelet." From this and the illustrations in his paper, it is beyond doubt that *Sumatrina* and *Neoschwagerina* refer to the same group of Foraminifera. The only point in which VOLZ differs from me is in regarding *Schwagerina craticulifera* SCHWAGER as a *Doliolina*¹⁾ and hence making a generic distinction between this species and *Sumatrina Annae*. On the contrary, I am inclined to treat *Sumatrina Annae* and *Schwagerina craticulifera* together as one group, quite distinct from *Doliolina* whose type is *D. lepida*.

There is a species of *Neoschwagerina*—*N. globosa* sp. nov.—in the upper complex of the limestones at Akasaka, possibly a variety of *N. craticulifera*; it possesses more numerous transverse septa than the type form in the lower complex, the longer and shorter septa being alternate; the same can be said of the auxiliary septa (Pl. I., fig. 5). Such being the case, I cannot help thinking that the 'Dachskelet' of *Sumatrina Annae* is but a shortened structure of the auxiliary and the transverse septa. If I am right, it is clear that *Sumatrina* is a synonym of *Neoschwagerina*. It is much to be regretted that VOLZ made no reference to *S. craticulifera* in describing his *Sumatrina*.

According to Dr. G. H. Girty, his new genus *Triticites* is distinguished from *Fusulina* by having the septa "for the most part straight and not fluted except in the immediate vicinity of the axis, so that the greater portion of each chamber is not divided into chamberlets." The genotype is *T. secalicus* SAY sp. from the Coal Measure of the Mississippi valley. I would here

1) Ditto, p. 24.

express my great obligation to Dr. Girty who was kind enough to send me some specimens of the Foraminifera, thus enabling me to verify his description of them. As I examined their sections under the microscope, I was fully convinced of the correctness of his remarks on the peculiar structure of the form; yet I am still in doubt whether it is possible to separate satisfactorily the American form from the group of *Schwagerina* with a fusiform shell, such as *S. fusulinoides* SCHELLWIEN and *S. fusiformis* KROTOW. The former, according to SCHELLWIEN, has "die grosse Centralkammer, die Hin- und Herbiegung der Septen, die in der median Ebene nie den Boden erreichen, Merkmale welche den Fusulinen zukommen," while *Triticites secalicus* possesses, beside these characters, the thick septa of a *Fusulina* s. s. Therefore, until more important differences from *Fusulina* s. s. and *Schwagerina* are found, it seems to me unnecessary to keep *Triticites* as a distinct genus, or even as a new subgenus.¹⁾

In addition to the above, let me remark briefly on some of the characters of *Fusulina*, which have been treated in detail by MÖLLER, SCHWAGER and SCHELLWIEN. The first thing to be noticed among these characters is the presence of connecting lamellae, which are found between the septa or between the septa and the wall. They are somewhat different in nature from the ramification of the primary septa, common in *Fusulina*. The occurrence of these connecting lamellae is very inconstant, and probably of no great significance. I once or twice met with lamellae of this kind in the transverse and longitudinal sections of *F. japonica* GUÉMBEL var. from Tomuro, Asogori, prov. Shimo-

1) However, I am inclined to believe that a similar name will be needed in future for the prototype of *Fusulina* and *Schwagerina*, and its direct descendants, if such really occur. See p. 21.

tsuke, Japan (Pl. II., fig. 1). Under the microscope, they appear as dark compact lines quite distinct from the septa. They may perform the same function as the ramifications or infoldings of the primary septa, or the intercalations of auxillary and transverse septa, subdividing the chambers or chamberlets.

Secondly, I am in doubt about the following remark of Prof. SCHELLWIEN.¹⁾

“Es tritt sehr häufig eine Verdickung der zum Septum umgebogenen Kammerwand ein, indem sich auf einer oder beiden Seiten der Septallamelle Kalksubstanz absetzt, welche in der Regel dunkler gefärbt.....Sie wird in der Regel erst nach der Bildung der neuen Kammerwand ausgeschieden zuweilen aber auch schon, ehe die Bildung der späteren Dachwand erfolgt ist, wie eine Beobachtung bei *Fusulina japonica* lehrt.” In all my slices of *Fusulina* I can find nothing which coincides with the above description; nor does the figure in his work to which he refers show anything of the kind. In all cases, the boundary between the calcareous substance of the primary septa and what he regarded as produced by a secondary accretion is not distinct and under the microscope they always seem to fade away on both sides.

Thirdly, the true nature of the median lamella, which is the direct continuation of the thin covering on the whole surface of the wall, is also doubtful. Dr. Girty has already objected to the long accepted view of the poriferous nature of the wall.²⁾ Though I am not in position to express anything definite here in regard to this matter, I give in fig. 3, pl. III., an interesting case of a natural staining of the wall. The figure shows a longitudinal, slightly oblique section, of *Neoschwagerina craticulifera* in a

1) SCHELLWIEN: Die Fauna des Karnischen Fusulinenkalks. P. 240.

2) Girty: l.c.

limestone block found in a Shiwon-cutting near Sakawa, province of Tosa. In microscopic sections, it almost always happens that the thin upper layer of the wall together with the median lamellae is stained deep brown, while those parts of the walls and the septa which appear to be thoroughly perforate, remain almost unstained. This fact seems to be in favour of the view that the median lamellae of the septa and the covering layer of the wall are of a different nature from the rest of the shell; but from this, I would not directly conclude the non-porosity of the shell.

SCHELLWIEN made mention of a particular case of the formation of septa in *Schwagerina* of the group of *Schwagerina Verbeeki*, saying "Es tritt nämlich häufig eine Verdickung des Septums ein, ehe die neue Kammerwand gebildet wird, wodurch bei der geringeren Stärke des Septums leicht der Anschein erweckt werden kann, dass die Scheidewand eingekeilt wäre. Diese Verdickung legt sich als ein dünner Beleg über das Septum."¹⁾

Taking these points in consideration, it appears to me that the whole external surface of the shell and of the septa of some, if not all *Fusulina*, is covered with a thin exogenous shell layer as in some other highly organized Foraminifera (for example, some species of the Genus *Rotalia*).

Fourthly, the infolding of the septa seems sometimes, though probably seldom, to occur also in the middle portion of the shell of *Schwagerina* as in *Fusulina* s. s. Such a case is seen in the outermost whorl of *Schwagerina princeps*, in a transverse section, from east of Yang-chao-shan, Wei-nung-hsien, prov. Kwei-tschou in China, as shown in fig. 1, pl. I.

Fifthly, '*Sumatrina*' *Annae* is said to possess, an extremely

1) SCHELLWIEN: l.c., p. 258.

large chamber, and indeed that of *Fusulina* s. s. usually attains a large size ; but in other subgenera the large chamber is of rare occurrence. Thus, *Schwagerina* is generally taken as including those forms which have a minute first chamber. Now, I go so far as to question whether the size of the first chamber is in any measure constant, for I have an example of a *Neoschwagerina* with a large first chamber, but quite similar to *N. craticulifera* in other respects (Pl. I., fig. 4).

The genus *Fusulina* has a very wide geographical distribution ; consequently there is a considerable number of works relating to its occurrence in various parts of the world, many of which are not accessible to me. Moreover, it seems that not much reliance can be placed upon the statements of its occurrence, as we do not know whether in all cases the specific names are used in the sense taken by us. These and other circumstances render an exhaustive treatment of its distribution impossible ; still we can get a general survey of the genus from the following summary of the more important literature of the subject.

American Border of the Pacific.

North America:—The distribution of *Fusulina*-limestone in North America is very extensive. Though *Fusulina* s. s. seems to be common in the above region, singularly, *Doliolina* and *Neoschwagerina* are at present very little known. Of *Fusulina*, especially the name of *F. cylindrica* FISCHER in its varieties is most frequently met with in the literature of the American Carboniferous ; thus we find them reported from the Subcarboniferous limestones of Colorado, Kansas, Ohio, Nebraska, Iowa, Indiana, California, Wyoming, Utah, Illinois, Arizona and British

Columbia.¹⁾ Unfortunately, none of them are fully illustrated, and it is by no means certain that they all belong to the same species. Schellwien²⁾ is of the opinion that some of the specimens of the so-called *F. cylindrica* from Iowa, Illinois, Indiana and Nebraska are distinct from the well known Russian species. *Triticites secalicus* SAY sp. from the Missouri region is one which was usually accepted as *Fusulina cylindrica*, but it has lately been separated from it by GIRTY and even made the type of a new genus. Beside these forms, SHUMARD³⁾ described *F. elongata* from New Mexico and Texas, and SCHELLWIEN⁴⁾ and SPANDEL⁵⁾ found *F. cfr. regularis* SCHELLWIEN in Kansas, Nebraska and Indiana. According to GIRTY⁶⁾ *F. elongata* SCHUM. occurs associated with *Productus semireticulatus* var., *Derbya*, *Meekella*, *Leptodus*⁷⁾ and *Richthofenia* in an upper Permian limestone of Western Texas. The last two genera of Brachiopoda being almost exclusively asiatic type, their record from the American Permian is specially noteworthy. Of *Schwagerina*, we know only *S. robusta* MEEK⁸⁾ from California found together with *F. cylindrica* and its variety *gracilis* (Mc Claud limestone, Boss' ranch).

1) There is, indeed, a multitude of articles relating to the North American *Fusulina*. Those published before 1897 are found in S. WELLER's "A Bibliographic Index of North American Carboniferous Invertebrates" (Bull. U. S. Geological Survey, No. 153, 1898). 'Manual of Geology' of J. D. DANA (4th Edition), amongst others, gave me a fair understanding of the distribution of the fossiliferous deposits and their kinds. The later publications at my disposal are: G. H. GIRTY: The Carboniferous Formations and Fauna of Colorado. U. S. Geol. Surv. Prof. paper, No. 16, 1903. Do: The Relation of Some Carboniferous Fauna. Proc. Washington Acad. Sci. 1905. F. L. RANSOME: The Geology and Ore-deposits of the Bisbee Quadrangle, Arizona. U. S. Geol. Surv. Prof. p. No. 21, 1904.

2) SCHELLWIEN: Die Fauna des Karnischen Fusulinenkalks, p. 280.

3) B. F. SHUMARD: Notice of New Fossils from the Permian Strata of New Mexico and Texas. Trans. St. Louis Acad. Sci. Vol. 1. 1858.

4) SCHELLWIEN: l.c. p. 251.

5) E. SPANDEL: Die Foraminiferen des Permocarbon von Hooser, Kansas, Nordamerika.

6) GIRTY: The Upper Permian in Western Texas. Amer. Journ. Sci. 1902.

7) *Leptodus* = *Lyptonia*.

8) F. B. MEEK: Description of the Carboniferous Fossils. Pal. Calif. Vol. 1, 1861.

Concerning *Neoschwagerina craticulifera* SCHWAGER from British Columbia, very recently communicated by SCHELLWIEN,¹⁾ no detail have yet been published.

Guatemala :—In the departments of Quiche, Huehuetenango, Alta-and Baba-Verapaz there exist thick limestone and dolomite-deposits probably of the uppermost Carboniferous. The fauna in addition to *Fusulina granum avenae* F. Römer which is a form first described from near Padang, Sumatra, consists of *Athyris, ambigua* David., *Synocladia*, *Productus semireticulatus* Mart. and *Lonsdaleia floriformis* Flem. sp.²⁾

Asiatic Border of the Pacific.

Vladivostock :—*Fusulina*-limestone occurs along the coast of the Ussuri bay between the mouth of the river Mai-cha and Zymucha. According to Th. TSCHERNYSCHIEW,³⁾ the *Fusulina* shows a peculiar form, being very long and having numerous (17–20) close volutions. Associated fossils are *Camarophoria Margaritowi* TSCHERN., *C. sp.*, *Reticularia rostrata* KUT., *Productus irginæ* STUCK., and *P. cora* D'ORB. The author believes that the limestone corresponds to the *Schwagerina*-zone of Eastern Russia.

Korea :—In this peninsula, *Fusulina*-limestone is exposed near Phyong-yang. It will be described at some length later on.

Japan :—We encounter *Fusulina*-limestone in various parts of Japan: in the main island (Honshū), in Shikoku, and in

1) SCHELLWIEN: Trias, Perm u. Carbon in China. 1902.

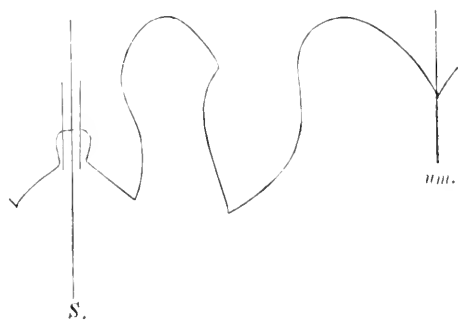
2) C. SAPPER: Grundzüge der Physikalischen Geographie von Guatemala. Petermans Mittheilungen. Ergänzungshefte No. 113. 1894. No. 127. 1899. *Fusulina* is said to be also found in a graywacke in this place.

3) TSCHERNYSCHIEW: Die Oberkarbonischen Brachiopoden des Ural u. des Timan. Mémoires du Comité Géologique. Vol. XVI., No. 2. 1902, p. 731.

Kiushū; but thus far there is no evidence of its occurrence in Hokkaido (Yesso) and the Kurils (Chishima) in the north, or in Formosa (Taiwan) and the Loo-choo (Riukiū) in the south. Nothing is known at present of its occurrence in the southern half of Saghalien (Karafuto). Almost invariably the species of *Fusulina* are found in limestone, but there is a single instance of its occurrence in a slate, (as in 'Auerniggschichten' of the Carnic Alps), at Maiya, prov. Rikuzen, where the slate underlies the *Fusulina*-limestone.

The poverty of other fossils in *Fusulina*-limestones excepting crinoid remains seems to be a character not only peculiar to Japan and China, but also to the rest of the world. The limestones contain a rich fauna of Brachiopoda, with which Cephalopoda are rarely associated, only when *Fusulina* is present in very small numbers. They, no doubt, are a littoral formation, and this is the reason why Cephalopoda are also almost always lacking in the Japanese Anthracolitic fauna.¹⁾

1) The Japanese Anthracolitic Cephalopoda which are now known are only three. Of these two being quite imperfect in preservation but one deserves some notice. This is moreover very incomplete being in the state of a cast. The shell is small, diameter measuring 23 mm., with a large umbilicus and broad whorls, deeply covering the inner ones. The ventral side is broadly rounded, the whorls being lunular in cross section. No periodic grooves are impressed on the cast. The suture lines are beautifully shown; they are rather distant, simple and very characteristic, composed of two saddles and two lobes on one side of the shell. They may better be understood from the annexed woodcut in four times the natural size. From this and other characters, I consider it to belong to a species of *Gastrioceras*.



The specimen, mentioned above, is from Ōmi, Nishi-kubiki-gōri, prov. Echigo, and comes in association with *Productus* cf. *spiralis* WAGG., *Spirifer* cf. *Oellombianus* WAGG., *P.* cf. *undatus* DILL., *Murchisonia*? sp. and *Schizophoria* *Verbeeki* CHINIZ.

It is not my intention in this place to enter into a detailed description of the stratigraphy of our upper Palaeozoic strata and faunal contents; a very condensed account of them is found in late Dr. T. HARADA's work 'Japanischen Inseln', and 'The Outlines of the Geology of Japan' issued by our Imperial Geological Survey. Some authors are accustomed to regard our *Fusulina*-limestones as belonging to one and the same horizon, but such an assumption is at present without foundation in fact and can only be settled by a careful investigation, both stratigraphical and palaeontological, of the limestones in question.

The only well known *Fusulina*-limestones of Japan are those of Kinshō-zan behind the small town of Akasaka, near the city of Ōgaki in the province of Mino. In this locality RICHTHOFEN got his fossils which SCHWAGER afterward studied. Geological studies of the district were subsequently undertaken by Professors GOTTSCHÉ,¹⁾ KŌTŌ²⁾ and WAKIMIZU.³⁾ All these investigators agree in accepting two grand divisions of the limestone deposits, which have been designated, (as in the Carnic Alps, and Russia), as the *Fusulina*-and the *Schwagerina*-limestone series respectively. Both series are again subdivided into a number of zones in which, however, they do not quite agree. I examined more than a hundred microscopic sections of the limestones brought from all of these zones, mostly by Mr. WAKIMIZU, and came to the conclusion that the distribution of *Fusulina* among them quite justifies the two grand divisions of the strata. The distribution of the Foraminifera in the respective divisions is as follows:⁴⁾—

1) C. GOTTSCHÉ: Ueber Japanische Carbon. Zeit. d. deutsch. geol. Gesell. Bd. XXXVI. 1884.

2) B. KŌTŌ: Classification of the Carboniferous Limestones of Akasaka (in Japanese). Journ. Geol. Soc. Tōkyō. Vol. V. 1898.

3) T. WAKIMIZU: Limestone Beds of Kinshō-zan, Akasaka (in Japanese). Ditto. Vol. IX. 190.

4) YABE: A Trip to Kinshō-zan (in Japanese). Ditto. Vol. XI. 1904. The Second Trip. (in Japanese). Ditto. Vol. XIV. 1906.

Upper division—*Schwagerina*-limestone series.

Schwagerina Verbeeki. Very rich in a certain zone, alone or in association with the next species.

Neoschwagerina globosa sp. nov. (Pl. I., fig. 5; Pl. III., fig. 1). Present in almost all the zones.

Lower division—*Fusulina*-limestone series.

Schwagerina Verbeeki. Rare.

Doliolina lepida. } These species are very
Neoschwagerina craticulifera. } abundant in a certain
 zone called "Samé", together with the next species.

Fusulina japonica.

Fusulina sp.

Neoschwagerina globosa. Very rare, if really present at all; I have once seen a doubtful trace of it in one of my slices.

The preponderance of *Neoschwagerina globosa* in the upper, and of *Fusulina* in the lower series makes the contrast very striking, and in this connection, there are two important facts to be mentioned:—(I) *Helicoprion Bessonowi* KARPINSKI, which was first found in the Artinskian of the Ural occurs at Hanawa, prov. Shimotsuke, in a limestone with abundant *Fusulina japonica* var.¹⁾ (II) *Neoschwagerina globosa* seems more closely allied to *N. craticulifera* of SCHELLWIEN found in the '*Doliolina*'-limestone lying immediately beneath a limestone with *Xenodiscus tangticus* SCHELLWIEN of the lower Triassic in Semenow mountains of north-eastern Tibet,²⁾ than to the typical *N. craticulifera* from Japan and China.

1) YABE: On a *Fusulina*-limestone with *Helicoprion* in Japan. Ditto. Vol. X. 1903.

2) E. SCHELLWIEN: Trias, Perm u. Carbon in China. Schriften d. Physikalökonom. Gesell. zu Königsberg. 1902. Paläozoische u. Triadische Fossilien aus China. FUTTLER'S Durch Asien III. 1903.

China :—*Fusulina*-limestones are extensively developed in various parts of China, in the provinces of Yun-nan,¹⁾ Se-tschuan,²⁾ Kan-su,³⁾ Kiang-si,⁴⁾ Kiang-su,⁵⁾ Hu-pei,⁶⁾ Kwei-schou,⁷⁾ and Tibet.⁸⁾ According to SCHWAGER,⁹⁾ LORENTHEY,¹⁰⁾ DOUVILÉ,¹¹⁾ and SCHELLWIEN,¹²⁾ they contain *Fusulina brevicula* SCHWAGER, *F. japonica* GÜMBEL, *F. Riechthofeni* SCHWAGER, *F. cylindrica* FISCHER, var. *gracilis* MEEK., *F. alternans* SCHELLW. *Schwagerina princeps* EHRENBERG, *S. Verbeeki* GEINITZ, *Doliolina lepida* SCHWAGER, *Neoschwagerina craticulifera* SCHWAGER, and a few other allied, but undeterminable forms. The limestones are referred to several distinct zones of different ages in the upper Carboniferous and Permian. Several specimens of them from China also have come into my hands through the courtesy of Messers JIMBŌ, YAMADA, OGAWA, and HIRABAYASHI; some of them are from places probably new to science, therefore it may be better to mention the localities of my samples, with the names of Foraminifera contained in them.

- 1) Ta-gai-tung, En-nang-hsien, prov. Yun-nan.¹³⁾ (YAMADA's coll. No. 31).

Fusulina sp.

Schwagerina Verbeeki

Neoschwagerina craticulifera

N. (Sumatrina) Anna

Besides, *Fusulinella* and *Bigenerina*.

1) 雲南

2) 四川

3) 甘肅

4) 江西

5) 江蘇

6) 湖北

7) 貴州

8) 西藏

9) SCHWAGER: Carb. Foram. aus China u. Japan. RICHTHOFFEN'S China IV.

10) E. LORENTHEY: Mikroskopische Untersuchungen der Palaeozoischen Gesteine SZECHENY'S Ostasien III. 1899.

11) H. DOUVILÉ: Examen des Foss. rapporté de la Chine par la mission LECLERE. Comptes Rendu. CXXX. 1900.

12) SCHELLWIEN: l.c.

13) 雲南省恩安縣大岩洞

- 2) Uchai, Ta-kuan, prov. Yun-nan.¹⁾ (YAMADA's coll. No. 35).

Schwagerina Verbecki

- 3) Ho-chang, between Ho-tung and Tsu-chung, Wei-mung-chou, prov. Kwei-schou.²⁾ (YAMADA's coll. No. 16.)

Fusulina sp.

Doliolina lepida

Besides, *Fusulinella* (the same species as the above).

Bigenerina, *Tetrataxis*.

- 4) Between Ho-tang and Hsia-ma-kwan, Wei-mung-chou, prov. Kwei-schou.³⁾ (YAMADA's coll. No. 13).

Fusulina cylindrica

- 5) East of Yang-chao-shan, Wei-mung-chou, prov. Kwei-schou.⁴⁾ (YAMADA's coll. No. 17).

Schwagerina princeps

- 6) East of Ho-tang, Wei-mung-chou, prov. Kwei-schou. (YAMADA's coll. No. 15).

Schwagerina sp.? not exactly determinable.

- 7) Che-hai, Hui-tso-hsien, Tong-chuan-fu, prov. Yun-nan.⁵⁾ (YAMADA's coll. No. 26).

Schwagerina ? not exactly determinable.

- 8) West of Man-kan-shan, Tien-chien-hsien, prov. Se-tschuan,⁶⁾ (YAMADA's coll. No. 37).

Fusulinella, the same form as found in the rocks No. 1 and 3.

- 9) Pong-tsze, prov. Kiang-si.⁷⁾ (coll. by JIMBO).

Fusulina sp. indet.

Besides, *Endothyra* and *Bigenerina*.

1) 雲南省大關廳五寨

2) 貴州省威寧廳后場(下馬崗)

3) 雲南省東州府會澤縣者海

7) 江西省彭澤

2) 貴州省威寧廳后場(黑塘英中)

4) 貴州省威寧廳羊角山

6) 四川省天全州門坎山

- 10) Northwest of Long-cha-chong, Ping-shing-hsien, prov. Kiang-si.¹⁾ (coll. by HIRABAYASHI).

Schwagerina Verbeeki

Neoschwagerina sp. nov. aff. *craticulifera*.

- 11) Liu-yüan-kang, Shin-ngan-hsien, prov. Kiang-si.²⁾ (coll. by HIRABAYASHI).

Schwagerina sp, indet. (*S. princeps*) ?

Fusulina sp.

- 12) Kwan-choang, Fu-liang-hsien, Kiang-si.³⁾ (coll. by HIRABAYASHI).

Fusulina sp. indet.

- 13) Temple of Lei-yin-ko, Yen-shen-chen, suburb of Po-shan-hsien, prov. Schan-tung.⁴⁾ (coll. by OGAWA).

Fusulina sp. indet.

- 14) Colliery of Nan-chao-ching, South-east of Po-shan-hsien, prov. Schan-tung.⁵⁾ (coll. by OGAWA).

Fusulina sp. indet.

Indo-australian-continental Border of the Pacific.

Luan-prabang, Indochina :—Near the base of the Trias, there is a limestone with *Lonsdaleia* and *Schwagerina*.⁶⁾

Tenasserim :—In a dark limestone are found, beside *Schwagerina Oldhami* NÄETLING, *Lonsdaleia salinaria* WAAGEN and WENTZEL, *Productus sumatrensis* ROEMER, *Pleurotomaria* aff. *durga* WAAGEN, and a few other fossils.⁷⁾

1) 江西省萍鄉縣龍家沖西北

2) 江西省興安縣柳源坑

3) 江西省浮梁縣官莊村

4) 山東省博山縣顏神鎮雷音閣下

5) 山東省博山縣南掉井

6) LAPARENT: *Traité de Géologie* III. edition, p. 942.

7) F. NÖETLING: Carboniferous Fossils from Tenasserim. *Rec. Geol. Surv. India*. XXVI. 1893.

Padang, Sumatra :—The lower *Fusulina*-limestone contains *F. granum arenar*, *F. sp.*, 5 species of *Bigenerina*, *Productus sumatrensis* ROEM, *Spirifer Damesi* FLIEGEL, *Bellerophon convolutus* v. BUCH, *Pleurotomaria Nikitini* FLIEGEL, *Naticopsis sumatrensis* ROEM., etc., while the upper *Doliolina*-limestone contains *Doliolina Verbeeki*, *Neoschwagerina craticulifera*, *N. (Sumatrina) Anna* VOLZ, and also rarely *Fusulina granum arenar*. FRECH, FLIEGEL and VOLZ¹⁾ believe the age of the *Doliolina*-limestone to be the uppermost Carboniferous.²⁾

Coasts along the Mediterranean Sea.

Persia :—According to MÖLLER,³⁾ the *Fusulina*-limestone of the eastern Albours-range contains *Fusulina Verneuli* MÖLLER and *Schwagerina princeps* EHRENBERG; these are associated with Brachiopoda such as *Orthotetes crenistria* PHILL. and *Productus semireticulatus* MART.

Turkestan :—In the Charat of Bokhara, close to the Turkestan frontier, there are two horizons of *Fusulina*-limestone, according to A. KRAFFT.⁴⁾ The *Fusulina*-limestone of the upper

1) F. ROEMER: Ueber eine Kohlenkalkfauna der Westküste von Sumatra. Paleontographica XXVII. 1880. F. FRECH: Die Steinkohlenformation, 1899. FLIEGEL: Die Verbreitung des Marinen Obercarbon in Süd- und Ostasien. Zeits. d. deutsch. geol. Gesel. Bd. L, 1898. W. VOLZ: Zur Geologie v. Sumatra.

2) *Fusulina*-limestone of Borneo is frequently mentioned in the literature of *Fusulina*, evidently copied from a note in the Geological Magazine of 1875. But according to FLIEGEL's comment in the Zeitschrift der deutschen geologischen Gesellschaft, the note in the Geological Magazine being an abbreviated translation of STACHE's paper which appeared in Verhandlungen der k. k. geol. Reichsanstalt, Borneo was originally an unfortunate misprint for 'Sumatra.'

KAYSER also made mention of occurrence of a *Fusulina*-bearing rock in Timor (Geolog. Formationskunde II edition 1902), but nothing is known at present about its details.

3) MÖLLER: Ueber Einige Foraminiferen-führende Gesteine Persiens. Jahrb. d. k. k. geol. Reichsanstalt. Bd. XXX. 1880.

4) A. KRAFFT: Geologische Ergebnisse einer Reise des Charat Bokhara. Denkschrift. d. k. Akad. Wiss. Mat. Nat. Klasse. Bd. LXX. 1901.

Carboniferous attains a thickness of almost 300 m. and contains *Fusulina* sp., a characteristic short and swollen form with irregular spirals. This limestone is followed above by a younger complex of tuff, tuff-sandstones and black *Fusulina*-limestone. The last rock contains two different forms of *Fusulina*, one of which is an ally of *F. japonica* and probably identical with *F. Mölleri* described by ROMANOWSKY in the third part of his "Materialien zur Geologie des Turkestans", while the other resembles *F. brevicula* and *F. multiseptata*. The above determination of the fossils was made by SCHELLWIEN who, however, found no trace of *Schwagerina* and *Doliolina* in these limestones. According to BOGDANOWICH and SUSS,¹⁾ a limestone with *Fusulina* occurs also at Jatantschitag and on the southern flank of Tekelik-tag, eastern Turkestan. The latter regarded it of Moscow stage.

Salt-range:—The rich fauna of the lower *Productus*-limestone of the Salt-range also contains many forms of *Fusulina* s. s. The total absence of *Doliolina* and *Neoschwagerina* in this and other divisions of the Anthracolitic deposits and the corresponding deposits of the Himalayas gives to them an aspect very different from those of China. The species of *Fusulina* have been described by SCHWAGER,²⁾ who distinguished the following species: *F. kattaensis* SCHWAGER, *F. pailensis* SCHWAGER, *F. longissima* MÖLLER, *F.* sp. indet. The occurrence of *F. longissima* MÖLLER (this specific identification is sometimes disputed), formerly restricted to Russia, is very important. The fauna accompanying the *Fusulina* of the Salt-range is too well known to be repeated in this place.

Balia Maaden and Cilician Tarsus, Asia Minor:—According

1) E. SUSS: Beiträge z. Geol. u. Paleont. Centralasiens.

2) SCHWAGER: Protozoa in Salt-range Fossils. Pal. Indica. Ser. XIII, I, 7. 1887.

to ENDERLE¹⁾ and SCHELLWIEN, many forms of *Fusulina* occurs in a complex of limestones of Hadi Veli Oglou and Aktchal Dagħ near Balia Maaden. From Hadi Veli Oglou, Schellwien mentions *Doliolina* aff. *lepada*, *Neoschwagerina craticulifera*, *Schwagerina princeps*, *Fusulina japonica* and *F. tenuissima* which are in association with *Productus* cfr. *sumatrensis*, *Naticopsis*, *Bellerophon*, *Pleurotomaria*, *Murchisonia* etc. while from Aktchal Dagħ *N. craticulifera* and *S. princeps* are recorded.

Also in Cilician Tarsus, a limestone with *Fusulina cylindrica* seems to occur.

Island of Chios :—We owe much to TELLER²⁾ for our knowledge of the existence of a *Fusulina*-limestone in this island. STACHE,³⁾ who made a study of the collection made by Teller, mentions the existence of *F. Suessi* STACHE and *F. elongata* SCHUM. in the limestone.

Palermo, Sicily :—In 1872, Permian limestones with a rich fauna were found in the Sosio valley in the Province of Palermo in Sicily. The fauna has been described in detail by GEMMELLARO⁴⁾ and is remarkable for the numerous Cephalopoda that it contains (fifty nine species of Ammonites and eighteen species of Nautilus), showing an affinity on one side to the Artinskian forms, and in the other, to some of the *Productus*-limestones. The two genera of Brachiopoda, *Richthofenia* and *Leptodus*, characteristic of the Asiatic Permocarboniferous deposits, are also known from this place. At Rocca di S Benedetto, the *Fusulina*-limestone is described as covered by a loose 'Calcare Grossalono.' To my

1) J. ENDERLE: Ueber eine Anthracolithische Fauna von Balia Maaden in Kleinasien. Beitr. z. Geol. u. Paleont. Osterr.-Ung. u. Orient. Bd. XIII. 1900.

2) Denkschrift d. k. Akad. d. Wiss. Mat. Nat. Classe. Bd. XL. p. 344.

3) Verhandlungen d. k. k. geol. Reichsanstalt. 1879. p. 371.

4) G. G. GEMMELLARO: La Fauna del Calcare con Fusulina. 1887-88.

regret, details about the species of *Fusulina* are unknown to me as in the case of the Island of Chios, Brazil and North America.

Carnic Alps :—The *Fusulina*-limestones and the fauna contained therein have lately been treated in details by FRECH, SCHELLWIEN and GORTANI.¹⁾ SCHELLWIEN distinguished the following four horizons of the limestones according to the distribution of the species of *Fusulina* :—

4) Highest zone (Troglkofelschichten).

Fusulina alpina SCHELLW. var. *communis*?

Fusulina regularis SCHELLW.

Schwagerina fusulinoides SCHELLW.

Schwagerina princeps EHRENB.

Beside the above forms, there are also *Steinmannia*, a genus of calcareous sponge also found in the Salt-range and in Japan,²⁾ *Productus cancerini* VERN., *Scaphinella variabilis* GEMM., *Spirifer tibetanus* DIENER, *Spirifer Wynnei* WAAGEN, *Thalassoceras microdiscus* GEMM., *Popanoceras* sp. etc.

3) Zone of a *Schwagerina*-limestone.

Fusulina alpina var. *communis*

Fusulina multiseptata SCHELLW.

Fusulina tenuissima SCHELLW.

Schwagerina princeps.

2) The principal zone of *Fusulina*.

Fusulina alpina var. *fragilis*

1) E. SUSS: Ueber das Vorkommen von Fusulinen in den Alpen. Verh. d. k. k. geol. Reichsanstalt. 1870. F. FRECH: Die Steinkohlenformation. 1899. E. SCHELLWIEN: Die Fauna des Karnischen Fusulinenkalks II. Theil. Paleontographica Bd. XLIV. 1898. M. GORTANI: Fossili rinvenuti in un primo saggio del calcare a *Fusuline* di Forni-Avoltri (alta Carnia occidentale). 1903. (by review). Do: Sul rinvenimento del Calcare a *Fusulina* presso Forni-Avoltri nell alta Carnia occidentale. 1902. (by review).

2) YABE: Materials for a Knowledge of the Anthracolitic Fauna of Japan. Journ. Geol. Soc. Tokyo. Vol. IX. 1902.

Fusulina alpina communis

Fusulina multiseptata

Fusulina regularis

Fusulina incisa SCHELLW.

1) The lowest zone of *Fusulina*.

Fusulina alpina var. *antiqua*

Fusulina alpina var. *communis*.

Fusulina tenuissima

In the lowest zone there are also *Amblysiphonella* sp., *Lonsdaleia floriformis* FLEM., *Spirifer fasciger* KEYS., *S. trigonalis* MART., var. *lata* SCHELLW., *Reticularia lineatus* MART., *Productus semireticulatus* MART.

Asturia, Spain :—A *Fusulina*-limestone forms the base of the upper Carboniferous exposed in the district; it contains, beside *Fusulina cylindrica* and some other forms of the same genus, an important leading fossil *Spirifer mosquensis*.¹⁾

Para, Brazil :—The Carboniferous fauna of Tapajos is very rich in Corals, Crinoids, Bryozoa, Brachiopoda, Lamellibranchiata, and Gasteropoda, while *Fusulina* is very rare. The last is reported to occur at Itaituba.²⁾

Russian Sea.

Russia :—In central Russia, the upper Carboniferous series is divided into two well known groups :—the lower or Moscovian stage (horizon of *Spirifer mosquensis*) and the upper or Gshelian stage (horizon of *Chonetes uralica*).

In the upper Carboniferous rocks of the Ural mountains, two

1) MEUNIER reported the occurrence of a limestone containing *Fusulina* at Morvan, central France, but according to F. FRECH, it is not a true *Fusulina* but a *Fusulinella*.

2) KATZER: Grundzuge der Geologie des unteren Amazonas Gebietes, 1903.

faunistically different horizons may be likewise distinguished :—the lower (C_2) (horizon of *Spirifer mosquensis*) and the upper (C_3) (horizon of *Productus cora*). The latter is a *Fusulina*-limestone and is covered by that of *Schwagerina*.

In the Oka-Kljasma and Oka-Wolga basins, the horizon of *Chonetes uralica* is overlaid by *Schwagerina* Dolomite.

As may be seen from the above, the *Schwagerina*-limestone of the Ural mountains, must be placed on a somewhat higher level than the Gshelian stage. The Artinskian marls and sandstones (Cpg) conformably overlie the *Schwagerina* horizon.

The species of *Fusulina* which is a genus very widely distributed in the Russian Carboniferous and Permian, was fully worked out by MÖLLER a quarter of a century ago. According to the works of MÖLLER, and those of KROTOW, STUCKENBERG, SIBIRIZEW, and TSCHERNYSCHEW¹⁾ which subsequently appeared, I

	Moskau stage	<i>Cora</i> stage	<i>Schwagerina</i> stage	Permo-carboniferous
<i>Fusulina Boeki</i>	—	—	×	—
<i>cylindrica</i>	×	×	—	—
var. <i>gracilis</i>	?	?	—	—
<i>longissima</i>	?	×	×	×
<i>montipara</i>	×	×	×	×
<i>prisca</i>	×	×	×	—
<i>uralica</i>	—	×	×	—
<i>ventricosa</i>	?	×	×	—
<i>Vennuili</i>	×	×	×	×
<i>Schwagerina fusiformis</i>	—	—	×	—
<i>princeps</i>	—	×	×	×
<i>robusta</i>	—	×	×	—

1) EHRENBURG: Mikrogeologie. BRADY: Notes on a Group of Russian Fusulinae. Ann. Mag. Nat. Hist. 1876. FRECH: Die Steinkohlenformation. TRAUTSCHOLD: Die Kalkbrüche von Mjatschkowo. Nouv. Mem. de la Soc. Imp. d. Naturalistes de Moscou. 1874-76. TSCHERNYSCHEW: Note sur le rapport des dépôts carbonifères russes avec ceux de l'europe occidentale. Ann. de la géol. du Nord. Bd. 17. 1890. (by review). DO: Die Obercarb. Brachiopoden des Ural u. des Timan. KROTOW: Geologische Forschungen am westl. Ural-Abhänge in den Gebieten von Tscherdyn u. Ssolikansk. 1888. STUCKENBERG: Allgemeine Geologische Karte von Russland. Mém. comité Géol. XVI., 1898. SIBIRIZEW: Allgemeine Geol. Karte v. Russland. Ibid. XV., 1896. Guide des Excursions du VII. Congrès Géologique International.

have made the above mentioned table of the vertical range of the most important species of Russian *Fusulina*.

C. v. Voight has found a limestone with abundant *Schuragerina princeps* near Symperopol in the Crimean peninsula, this is an important discovery, for it indicates the existence of an open connection between the Russian and the Mediterranean sea in the Carboniferous time.¹⁾

Arctic Ocean.

Spitzbergen:—J. G. ANDERSON and GÖES²⁾ observed a limestone with *Fusulina cylindrica* and *Spirifer mosquensis* in Spitzbergen; but TSCHERNYSCHEW doubts the correctness of the determination of the *Fusulina*. The limestone overlies the Culm deposit and the Devonian.

Bear Island:—We owe to ANDERSON our knowledge of the existence of a *Fusulina*-limestone of the middle Carboniferous age in this Island. According to this author, the fauna consists of *Fusulina cylindrica* FISCHER. *Camarophoria isoryncha* M'COY, *Syringopora ramulosa* GOLDF. and a Cyathophylloid coral.

Prince Albert Land:—Salter described a *Fusulina* from the Carboniferous limestone of this island under the name of *F. hyperborea*, a form closely allied to *F. longissima* according to MÖLLER.

The next table, imperfect as it is, owing to the want of uniformity in the limit of species among various authors, clearly

1) TSCHERNYSCHEW: Die Obecarbonischen Brachiopoden des Ural u. des Timan. p. 681.

2) ANDERSON. Ueber die Stratigraphie u. Tectonic der Baren-insel. Bull. Geol. Inst. Upsala, 1900. GÖES: Oefvers. Vet. Akad. Forhandl. 1883.

shows that *Neoschwagerina* and *Doliolina* (including *Sumatrina*) have their distribution almost entirely confined to the Pacific ocean, which seems to be their proper habitat.

Studying the *Fusulina* of the Carnic Alps, SCHELLWIEN arrived at an important conclusion.¹⁾ According to this author, species of *Fusulina* s. s. bear a local nature in striking contrast to *Schwagerina princeps* and many other allied forms, which show a wide distribution. TSCHERNYSCHEW,²⁾ however, considered this view as direct contradiction to the theory of derivation of *Schwagerina* from *Fusulina* s. s. and pointed out the occurrence of some Carnic species and a variety of Salt-range species in the Russian Carboniferous. Be that as it may, it seems to me that the derivation of *Schwagerina* from *Fusulina* has no relation to the view maintained by SCHELLWIEN.

**Table showing the Distribution of the Important
Species of the Genus *Fusulina*.³⁾**

	Pacific Ocean.					Mediterranean Ocean.					Arctic Ocean.	
	Guatemala.	N. America.	Japan.	China.	Padang, Tenasserim.	Brazil.	Persia, Asia Minor etc.	Salt-Range.	S. Europe.	Russian Sea.	Fr. Albert isl.	Spitzbergen.
FUSULINA.	×	×	×	×	×	×	×	×	×	×	×	×
<i>alpina</i> var. <i>antiqua</i>	—	—	—	—	—	—	—	—	×	—	—	—
var. <i>communis</i>	—	—	—	—	—	—	—	—	×	—	—	—
var. <i>fragilis</i>	—	—	—	—	—	—	—	—	×	—	—	—
<i>alternans</i>	—	—	—	×	—	—	—	—	—	—	—	—
<i>Bocki</i>	—	—	—	—	—	—	—	—	—	×	—	—
<i>brevicula</i>	—	—	—	×	—	—	—	—	—	—	—	—
<i>complicata</i>	—	—	—	—	—	—	—	—	×	—	—	—

1) SCHELLWIEN: Karnischen Fusulinenkalk. p. 280.

2) TSCHERNYSCHEW: l.c. p. 280.

3) There are many other species of *Fusulina*, not enumerated below; for they have not been fully illustrated by the authors themselves; such are *F. Hefferi* STACHE, *F. Suessi* STACHE.

Table showing the Distribution of the Important
Species of the Genus *Fusulina*—(Continued.)

	Pacific Ocean.					Mediterranean Ocean.					Arctic Ocean.	
	Guatemala.	N. America.	Japan.	China.	Padang, Tenasserim.	Brazil.	Persia, Asia Minor etc.	Salt-Range.	E. Europe.	Russian Sea.	Pr. Albert isl.	Spitzbergen.
<i>cylindrica</i>	—	×	—	×	—	—	×	—	×	×	—	×
var. <i>gracilis</i>	—	×	—	×	—	—	—	—	—	×	—	—
<i>longula</i>	—	×	—	—	—	—	—	—	—	×	—	—
<i>exilis</i>	—	—	×	—	—	—	—	—	—	—	—	—
<i>granum arenae</i>	×	—	—	—	×	—	—	—	—	—	—	—
<i>hyperborea</i>	—	—	—	—	—	—	—	—	—	—	×	—
<i>incisa</i>	—	—	—	—	—	—	—	—	×	—	—	—
<i>japonica</i>	—	—	×	×	—	—	×	—	—	—	—	—
<i>kaltanensis</i>	—	—	—	—	—	—	—	×	—	×	—	—
<i>longissima</i>	—	—	—	—	—	—	—	×	—	×	—	—
<i>Möller</i>	—	—	—	—	—	—	×	×	—	×	—	—
<i>montipara</i>	—	×	—	—	—	—	—	—	—	×	—	—
<i>multiseptata</i>	—	—	—	—	—	—	—	×	×	×	—	—
<i>pauca</i>	—	—	—	—	—	—	—	×	—	—	—	—
<i>prisca</i>	—	×	—	—	—	—	—	—	—	×	—	—
<i>pusilla</i>	—	—	—	—	—	—	—	—	×	—	—	—
<i>regularis</i>	—	×	—	—	—	—	—	—	×	—	—	—
<i>Richthofeni</i>	—	—	—	×	—	—	—	—	—	—	—	—
<i>tennissima</i>	—	—	—	—	—	—	×	—	×	—	—	—
<i>uralica</i>	—	—	—	—	—	—	—	—	—	×	—	—
<i>ventricosa</i>	—	×	—	—	—	—	—	—	—	×	—	—
<i>Verniculi</i>	—	×	—	—	—	—	×	—	—	×	—	—
SCHWAGERINA	—	×	×	×	×	—	×	—	×	×	—	—
<i>fusiformis</i>	—	—	—	—	—	—	—	—	—	×	—	—
<i>fusulinoides</i>	—	—	—	—	—	—	—	—	×	—	—	—
<i>Oldhami</i>	—	—	—	—	×	—	—	—	—	—	—	—
<i>princeps</i>	—	—	×	×	×	—	×	—	×	×	—	—
<i>robusta</i>	—	×	—	—	—	—	—	—	—	×	—	—
<i>secalicus</i> (<i>Tricities</i>)	—	×	—	—	—	—	—	—	—	—	—	—
<i>Verbeeki</i>	—	—	×	×	×	—	—	—	—	—	—	—
FOLIOLINA	—	—	×	×	—	—	×	—	—	—	—	—
<i>leptida</i>	—	—	×	×	—	—	×	—	—	—	—	—
NEOSCHWAGERINA	—	—	×	×	×	—	×	—	—	—	—	—
<i>Anae</i> (<i>Sumatrina</i>)	—	—	×	×	×	—	—	—	—	—	—	—
<i>craticulifera</i>	—	—	×	×	×	—	×	—	—	—	—	—
<i>globosa</i>	—	—	×	×	—	—	—	—	—	—	—	—

1) After MÖLLER.

2) After TSCHERNYSCHEW.

3) Specific identity of the Salt-range and Russian forms was doubted by SCHELLWIEN.

The consideration of the vertical range of the genus *Fusulina* is also very difficult to summarize at present; for the geological age of the *Fusulina*-limestones of various parts of the world, is for most cases, still in dispute. For instance, there are two different views about the age of the lower *Productus*-limestone of the Salt-range¹⁾ and of the 'Doliolina'-limestone of the old Pacific coast; some regard them as of the uppermost Carboniferous, while others consider them as Permian.

It is evidently misleading to consider a species of *Fusulina* to have a much restricted vertical range: to give only one instance, *F. montipara* is common in all deposits from the zone of *Spirifer mosquensis* up to the Artinskian formation in Russia. But as is usually the case, there is of course a possibility of less longevity in the case of the more lately evolved forms which have attained a higher complication of structure.

The distribution of the four subgenera of *Fusulina* in time is fundamentally different from that of *Orbitoides* of the later Cretaceous and Tertiary. In this latter genus, we can count at present four principal subgenera, namely *Orbitoides* s.s., *Orthophragmina*, *Lepidocyclus* and *Miogyropsina*, which appeared in almost regular succession, each confining its distribution to a certain geological age, for example, *Orbitoides* s.s. to the Cretaceous, *Orthophragmina* to the Eocene, *Lepidocyclus* to the Oligocene and *Miogyropsina* to the Miocene.²⁾ In the case of *Fusulina*, such a replacement of an older type by a younger seems never to have happened; the species belonging to a

1) WAAGEN: Salt-range Fossils, Geological Result. Pal. India. LAPPARENT: Note sur les calcaires à *Productus* du Salt-range. Bull. Soc. Geol. France 1903. TSCHERNYSCHAW: Die Oberearb. Brachiopoden. NOETLING: Ueber des Verhältniss zw. *Productus*kalk und *Ceratitenschichten*. There are many other works by the last named author on this subject.

2) Some Italian authors deny to accept this view of Douvillé and Schlumberger on the geological range of the Foraminifera.

structurally lower type, retained for ages its characters rigid and unshifting, the times and circumstances produced highly structural types, but hardly influenced the survival of the ancestral forms.

The derivation of *Neoschwagerina* either from *Doliolina* or directly from *Schwagerina* is a point still undetermined; however, it is almost certain when tracing the development of *Neoschwagerina craticulifera* from the initial chamber onward, that the first numerous chambers are already with transverse septa though not with auxiliary ones. Therefore it is not impossible that *Neoschwagerina* is but an improved form of *Doliolina*, unless the basal skeletons are transverse septa much shortened by degeneration, contrary to my present belief.

The subgenus *Doliolina* is *Schwagerina*, only one step higher in structure, and their relationship is so close that the form known as *S. Verbeeki* may likewise be called *D. Verbeeki*.

Triticites secalicus and some other forms, included in *Schwagerina* by KROTOW and SCHELLWIEN, undoubtedly show vestiges of a common ancestral group from which the typical *Fusulina* and *Schwagerina* sprang. The prototype, we have many good reasons to believe, might have been an elongate form, either fusiform or cylindrical, composed of some number of closely coiled volutions and divided into chambers more or less completely formed by numerous stretched septa. Therefore if many of the lower Carboniferous forms of *Fusulina* could be found and their structural details made known, the mutual relations between *Schwagerina* and *Fusulina* s.s. would be cleared up.

NOTES ON A FUSULINA-LIMESTONE FROM KOREA.

The discovery of a *Fusulina*-limestone in Korea is especially noteworthy, as it proves the existence of Anthracolitic deposits in more or less extension in a land geologically little known.¹⁾

When I examined a slice of Korean limestone brought back by Mr. N. FUKUCHI, my attention was immediately attracted to small foraminiferal remains which I took for a *Fusulina* in a state of very bad preservation; but unfortunately other sections of the same rock, since prepared, did not reveal any more reliable forms. At my request, Mr. T. IKI of the Imperial Geological Survey, very kindly paid a good deal of attention to the subject, while inspecting mines in the peninsula, and brought back many specimens of limestones which he placed at my disposal for examination. These limestones are all from the neighbourhood of Phyong-yang.²⁾

Our knowledge of the *Fusulina*-limestone and its associated rocks in Korea is at present very imperfect; an area along the Tai-dong-gang³⁾ below Phyong-yang is coloured by GOTTSCHÉ in his geological map as Tertiary, while the surrounding region is

1) In one of my former papers, Mesozoic Plants from Korea (Journ. Sci. Coll. Imp. Univ. Tôkyô, Vol. XX., No. 8, 1905), I proved the Mesozoic age of a thick complex, on the evidence of a fossil flora, widely spread in a region including the greater part of the Kyong-syang-Do and a part of the Chhung-chhyong-Do and Chol-la-Do. The plants found in the slate which GOTTSCHÉ referred to the Carboniferous, on account of the occurrence of his supposed *Neuropteris* in it, though not yet studied in detail, so far as my own opinion is concerned, is probably of a Triassic age. Also there is some doubt about the occurrence of *Fusulina*-limestone in Korea mentioned by H. CRÉDNER (Elemente d. Geologie. 1897, p. 467) and G. FLIEGEL (Zeitschrift d. deutsch. geol. Gesell. Bd. L.); the original paper if there be one, is not accessible to me.

2) 平壤.

3) 大同江 (Tai-dong-river).

entirely included in the crystalline schists. In p. 869 of his text, he gives the following accounts of the younger complex:—

“? Tertiär. Die Hügel, auf denen Phyong-yang steht, zeigen theils am Ufer des Tatumg, theils an ihrem nördlichen Hänge folgendes Profil von unten nach oben :

- | | |
|--|--------------|
| 1. Feinkörniger Sandstein mit undeutlichen Pflanzenresten und bis 4 cm. grossen Kohlenschmitzen, durch eine 2 m. starke Conglomeratbank getrennt von | 70 m. |
| 2. gelblichen, auch schwärzlichen Mergeln, ohne Versteinerungen | 40 m. |
| 3. fest, graue Mergelschiefer, ohne Versteinerungen | 25 m. |
| 4. leicht zerreibliche Sandsteine mit einzelnen Geröllen | 5 m. |
| | <hr/> 140 m. |

In 1. fanden sich sowohl im unteren Theil, als in der Conglomerat-bank wohl erhaltene Kieselhölzer, welche Herr. Dr. J. FELIX in Leipzig als neue Arten der Gattungen *Araucarioxylon* und *Cedroxylon* erkannt hat. Die erstere Gattung ist nach seiner Mittheilung von Carbon bis in's Tertiär, die letztere vom Rhät bis in die Gegenwart nachgewiesen. Die Schichten von Phyong-yang, welche sich auch auf dem linken Ufer noch 15 li gegen Südost, im Ganzen auf 40 li verfolgen lassen, sind also rhätisch oder jünger. Das Liegende derselben bilden theils krystallinische Schiefer, theils (zwischen Phyong-yang und Sam-deung) Kalke von unbekannten Alter.”

Phyong-yang has long been known for some coal seams exposed in its environs, partly workable and of wide reputation

in the peninsula; FUKUCHI, in a report (in Japanese) of the coal-survey, briefly refers to the geology of the district as follows:

“Near Phyong-yang, there are three different rock series exposed:—(1) the Palaeozoic composed of slate and limestone, (2) the Phyong-yang series consisting of three parts, the upper composed of sandstones, the middle of alternations of sandstones and of at least three coal seams and the lower of shales, and (3) alluvial along the Tai-dong-gang. At three spots (one near Mun-syu-bong¹⁾ and two at Mu-no-san²⁾) a limestone with *Fusulina* was seen beneath the lower shale of the Phyong-yang series, but the exact relation between them is unknown.”

In one of his reports, Mr. T. IKI³⁾ also gives the similar result of his observation on this coal bearing series; he could not, as I am informed, make out a distinct stratigraphical break between the shale with the coal-seams and the same with the limestone-lenses. Besides, there is another series of sandstone exposed at the north of the Tai-dong-gang near Phyongyang which often contains imperfect impressions of plants and sometimes makes an approach to a conglomerate, with numerous inclusions of pebbles. The latter he doubtfully referred to mesozoic.

Although it is impossible at present to correlate the respective layers of the profile made by GOTTSCHIE with those of the one made by IKI and FUKUCHI, this much is certain, that the so-called Tertiary of the former corresponds, at least partly, to the coal-bearing series of the latter; for GOTTSCHIE had pointed out the occurrence of his Tertiary (?) deposit also at a place 15 Korean li (\doteq 6 km.) south of Phyong-yang, where there are no

1) 紋水峯 (Mt. Mun-syu).

2) 霧露山 (Mt. Mu-no).

3) Journ. Geol. Soc. Tōkyō, Vol. XIII, p. 173, 1906 (in Japanese).

other rocks than those of the coal-bearing series of IKI and FUKUCHI.

Admitting the correctness of FELIX and GOTTSCHÉ's view, there must be at least two divisions of rock series, one post-Rhætic and the other Anthracolitic. That there is a gradual transition between them is hardly conceivable; but the locality from which GOTTSCHÉ collected *Araucarioxylon* and *Cedroxylon* not being exactly known, the boundary between these two formations is at present also unknown.¹⁾

I found *Fusulina* in specimens of limestone from the following places near Phyang-yang:—

I) From a small exposure along the railway cutting near Kai-ka-dong²⁾ on the southern side of Mu-no-san (coll. by FUKUCHI).

The limestone is compact and dark-grey, traversed by numerous irregular fine calcite veins: microscopically no other organic remains than small circular sections of crinoid stems and

Fusulina sp. indet. aff. *Richthofeni* SCHWAGER
are found. The latter is very seldom in the rock.

II) Ko-pan-san,³⁾ in a valley of (coll. by IKI).

The limestone is black in colour and is carbonaceous, also with numerous fine calcite veins. Under microscope, we find

Fusulina sp. indet. aff. *Richthofeni* SCHWAGER.

Starcheia sp.

Bigennerina Bradyi MÖLLER sp.

Lagena sp.

1) At about 1½ ri (≐6 km.) west of Phyang-yang appears a thick complex of sandstone and shales of a nature similar to those to the east and south, but lacking limestone-lenses, and accompanying thick conglomerate beds. What is especially important in IKI's observation is the occurrence of limestone-pebbles in the above conglomerate. IKI took this formation as of decidedly younger age than the coal-bearing one, and therefore, it stands without relation to the present problem.

2) 開科洞

3) 古坊山 (Mt. Ko-pan).

III) Kotch-jiang-kol,¹⁾ west of the Sam-dennug²⁾ coal-field (coll. by IKI).

The limestone is extremely light coloured, with numerous small pullets of rather irregular form and size. Among the pullets are found numerous minute shells of Foraminifera, some of which probably belong to the young of *Fusulina*.

A similar rock is also reported by IKI and FUKUCHI as exposed near Mun-syu-bong. There is a limestone kiln, situated at the northern foot of Mu-no-san.

The geological age of this limestone is surely Anthracolitic, but to what part of it the rock belongs, is impossible to say.

DESCRIPTION.

FUSULINA sp. indet.

Pl. III., figs. 4 and 5.

Fig. 5, Pl. III. shows a transverse (slightly oblique) section of a *Fusulina* through its first chamber; it is the best I have ever seen in the thin slices of Korean limestone. This *Fusulina* is very small in size, with about four volutions, and attaining only 1.0 mm. in diam.; the volutions increase regularly and at the same time gradually in height, though they are not so closely coiled as in *F. japonica* GUEMBEL. The rate of growth of each volution is to be estimated as follows, -x-, x, x, 7, 9, 12, 14, 18, 20,....., the first three figures showing dimensions not capable of being measured with any accuracy. The walls are

1) 串場街

2) 三登

thin (nearly 0.03 mm. in the outermost volution) while the septa are still thinner. As was seen from one of the transverse sections, the latter become especially thin near the umbilical end. The shell has numerous septa which number about 30 in the fourth volution; infoldings of the septa are numerous and similar to those of *F. Richthofeni* SCHWAGER, except near the umbilical end.

Fig. 4 shows a longitudinal section, very excentrically made, of a *Fusulina*, whose specific identity with the above is rendered probable by its small size, the similarity in the relative thickness of the wall and septa, and above all by the absence of any other forms belonging to a clearly distinct species in many slices of the same rock. The areolar ramification of the septa at the umbilical end is not so conspicuous as in *F. Richthofeni*, a species which otherwise very much resembles our form in structure. This section, though taken very excentrically, also affords us some idea of the general aspect of the species; it may be called cylindrical rather than fusiform. The canals of the pores are simple, and have a breadth somewhat less than 0.01 mm.

In several respects, this Korean form is also not unlike *F. cylindrica* Fischer, though provided with many distinguishing features; for instance *F. cylindrica* has first chamber excessively large in comparison with our form; the ramification of the septa near the umbilical end is also not quite alike in these two.

From the above explanation of the accompanying figures, it will be seen that there is a peculiar small form of *Fusulina* s.s. in Korea, probably distinct from any of the described forms. I once took it for a local, dwarf variety of *F. Richthofeni*, a form hitherto found in China, but this needs verification from the examination of more numerous and better materials.

LAGENA sp. indet.

Pl. I., fig. 6.

With some hesitation, I refer a form known from a single longitudinal section to the genus *Lagena*. It appears to be pear-shaped, somewhat produced at one end, and has a thin calcareous and finely poriferous shell. I once met with quite a similar form while examining a slice of a 'Kuro' limestone of Akasaka, prov. Mino, which agrees with the Korean not only in outline and structure, but also in dimensions.

It attains 1.1 mm. in length and 0.6 mm. in breadth.

BIGENERINA BRADYI MÖLLER sp.

Pl. II., fig. 5.

Compare:

1876. *Textularia eximia* BRADY: Monograph of Carb. and Perm. Foram. P. 132, pl. X., figs. 27-29.
1897. *Cribrostomum Bradyi* MÖLLER: Foram. d. Russ. Kohlenkalk. p. 53, pl. III., figs. 1a-c; pl. VI., fig. 1, text figures 18, 19.

I compare the form represented in the above figure to *Bigenerina Bradyi* from the Russian and British limestones; the shell is small, attaining only 1.1 mm. in length and 0.55 mm. in breadth, composed of two rows of 4 and 5 alternating chambers which are then followed by a uniserial one. It appears in the section, more parallel sided than the typical form figured in the above cited works; this is probably due to the slight obliquity of the section from the median plane.

Its resemblance to the Russian and British species is very striking, and so that they at least show a close relationship to each other, if they are not really identical.

STACHEIA sp. indet.

Pl. III., fig. 6.

Fig. 6 shows a peculiar form. In a thin slice of a limestone, there is a peculiar form not hitherto met with in the *Fusulina*-limestones of Japan and China. In spite of its great imperfection, however, it seems to me to be a fragmentary specimen of a species of the genus *Stacheia*. It possesses only 7-8 concavo-convex chambers in succession each embracing previous ones except at its peripheral margin. These chambers are subdivided into numerous chamberlets by more or less radial partitions which are almost complete. The chamberlets are radially elongated and of a varying breadth. The wall and partitions are rather thin, uniform and imperforate; they appear granular, being preserved in quite a different manner from those of *Fusulina* and *Lagena* which occur in association.

If its determination as the genus *Stacheia* is correct, its occurrence in the Korean limestone is of some interest; for it is by no means a common genus, though not rare in some Carboniferous limestones of England,¹⁾ the Carnic Alps,²⁾ and European Russia.³⁾ *Stacheia Grewinki* MÖLLER⁴⁾ from Persia may

1) H. B. BRADY: A Monog. of Carb. and Perm. Foram. p. 107.

2) SCHELLWIEN: Die Fauna d. Karnischen Fusulinenkalks. p. 263.

3) MÖLLER: Die Foram. d. Russ. Kohlenkalks. p. 78.

4) MÖLLER: Ueber Einige Foraminiferenführende Gesteine Persiens. Jahrb. d. k.k. geol. Reichsanst. Bd. XXX. 1880.

probably belong to another genus. *Stacheia* has a range from Silurian to Lias.¹⁾

In conclusion, I desire to express my obligations to the gentlemen who have had the kindness to allow me to use materials collected by them. To Prof. M. Yokoyama, I also tender my best thanks for his courtesy in looking over this paper while in manuscript.

1) CHAPMAN counted six species of the genus in the Rhaetic rock of Somerset; some of them are indeed specifically identical with those of Carboniferous (CHAPMAN: Rhaetic Foraminifera from Somerset. Ann. Mag. Nat. Hist. XVI. 1895). Also a Devonian species found by SCHUBERT in a limestone of Bohemia is very like *S. polytrematoides* BRADY from Carboniferous. (R. J. SCHUBERT u. Ad. LIEBUS: Vorläufige Mittheilung ü. Foraminiferen aus dem Böhmischem Devon. Verh. d. k. k. geol. Reichsanstalt 1902. p. 66). Therefore, the Foraminifera though interesting in itself, has no value for geological correlation.

Postscript.

Very recently, Prof. YOKOYAMA found *Podozamites lanceolatus* and *Cladophraxis Whitbyensis* in a collection of plant-remains from Kam-peuk-nön near Phyong-yang. This confirms Mr. IKI's view, mentioned above; but without further knowledge on the geological relation existing between the plant bed and the coal bearing formation, the problem on the geological age of the latter above alluded to, is left unsettled for ever.

The remarkable occurrence of a peculiar, elongate species of *Fusulina* in a calcareous sandstone of Tsukitate, near Kesennuma, prov. Rikuzen, was accidentally omitted in the note on Japanese *Fusulina* (p. 11).

H. YABE.

A CONTRIBUTION TO THE GENUS FUSULINA.

PLATE 1.

Reference to Plate I.

- Fig. 1. *Schwagerina princeps* EHRENBERG, from the east of Yang-chao-shan, China. Transverse section. $\times 20$.
- Fig. 2. *Schwagerina Verbeeki* GEINITZ, from Tochikubo, prov. Iwaki, Japan. Longitudinal section. $\times 20$. a, septa; b, basal skeleton.
- Fig. 3. *Neoschwagerina craticulifera* SCHWAGER, from Akasaka, prov. Mino, Japan. Longitudinal section. $\times 20$.
- Fig. 4. *Neoschwagerina craticulifera* SCHWAGER, with a large first chamber, from Ōkubo, prov. Bitchū, Japan. Cross section. $\times 18$.
- Fig. 5. *Neoschwagerina globosa* YABE, from Akasaka, prov. Mino, Japan. Longitudinal section. $\times 48$. a, long transverse septa; b, short transverse septa; c, primary septa in a parallel section. Notice the fine poriferous nature of the wall and the upper portion of the septa.
- Fig. 6. *Lagena* sp. indet., from P'yong-yang, Korea. Longitudinal section. $\times 48$.

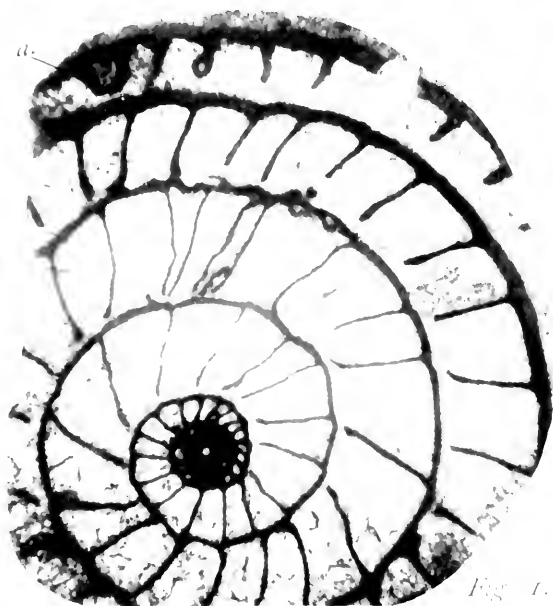


Fig. 1.

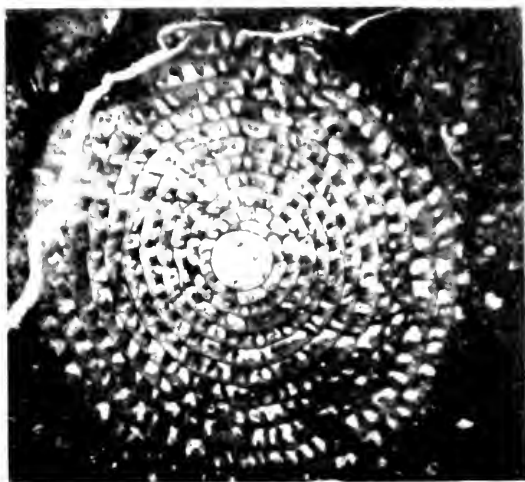
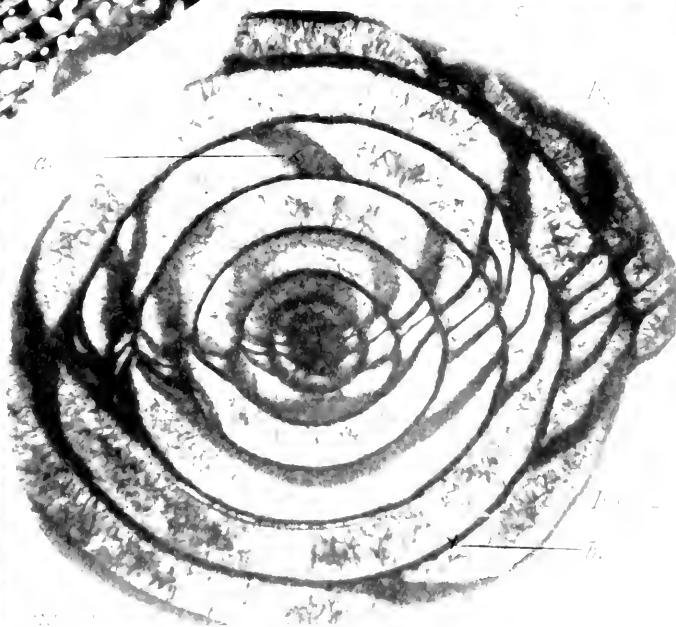
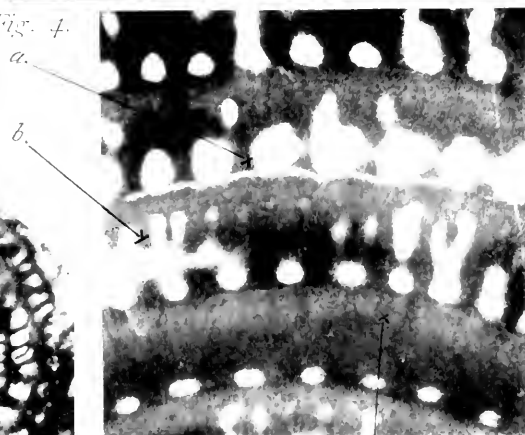
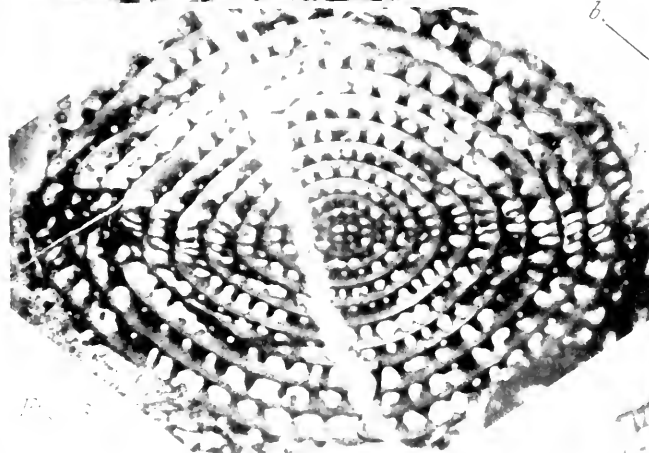
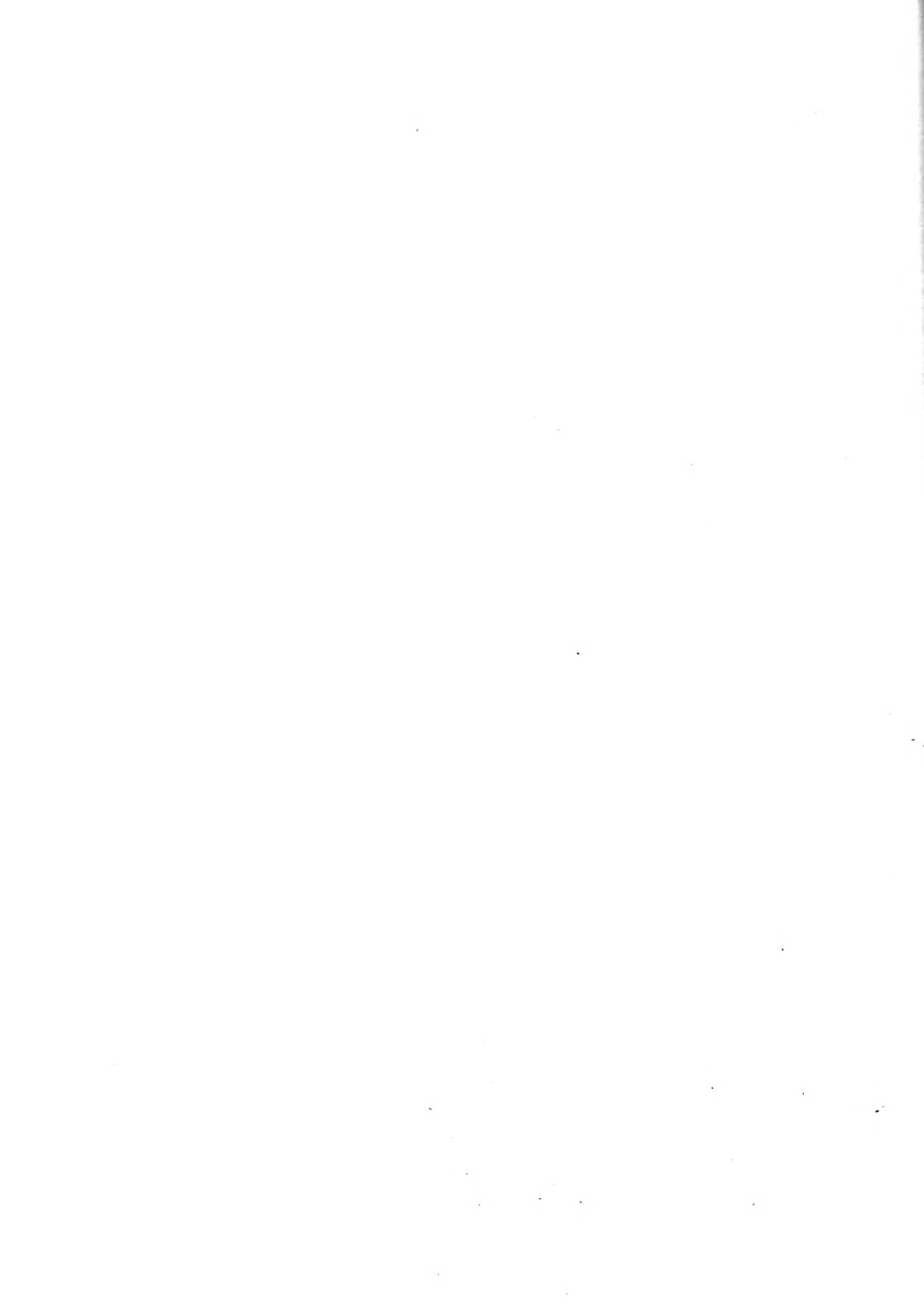


Fig. 4.





H. YABE.

A CONTRIBUTION TO THE GENUS FUSULINA.

PLATE II.

Reference to Plate II.

- Fig. 1. *Fusulina japonica* GÜMBEL var., from Asogori, prov. Shimotsuke, Japan. Longitudinal section. $\times 20$. a, connecting lamella.
- Fig. 2. *Doliolina lepida* SCHWAGER, from Akasaka, prov. Mino, Japan. Cross section, taken somewhat excentric. $\times 48$. a, basal skeleton, in a parallel section.
- Fig. 3. Ditto. Longitudinal section, taken somewhat excentric. $\times 48$. a, basal skeleton; b, primary septa.
- Fig. 4. *Neoschwagerina Annae* VOLZ, from Ōkubo, prov. Bitchū Cross section. $\times 20$.
- Fig. 5. *Bigennerina Bradyi* MÖLLER? from Phyang-yang, Korea. Longitudinal section. $\times 48$.

Fig. 1.

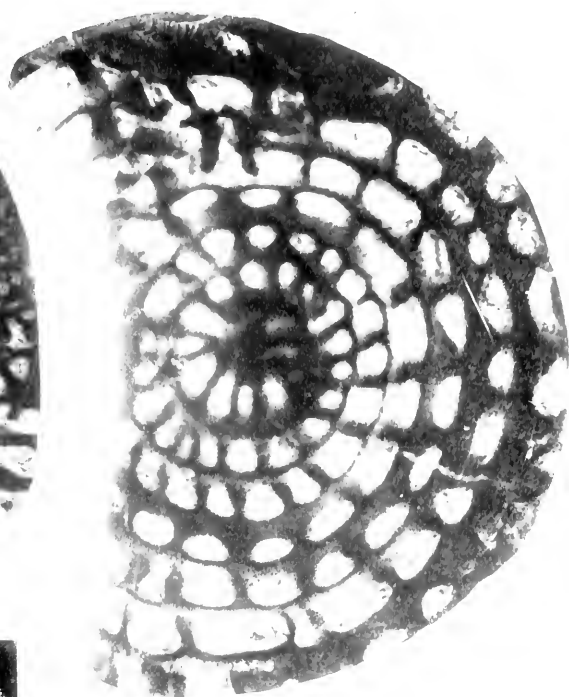


Fig. 4.

a.

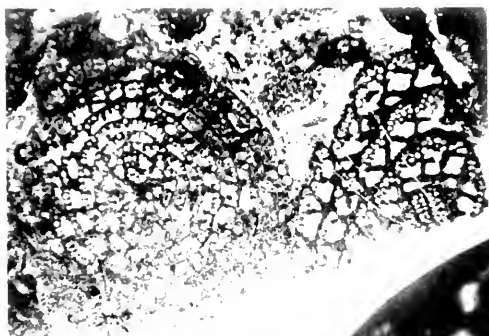
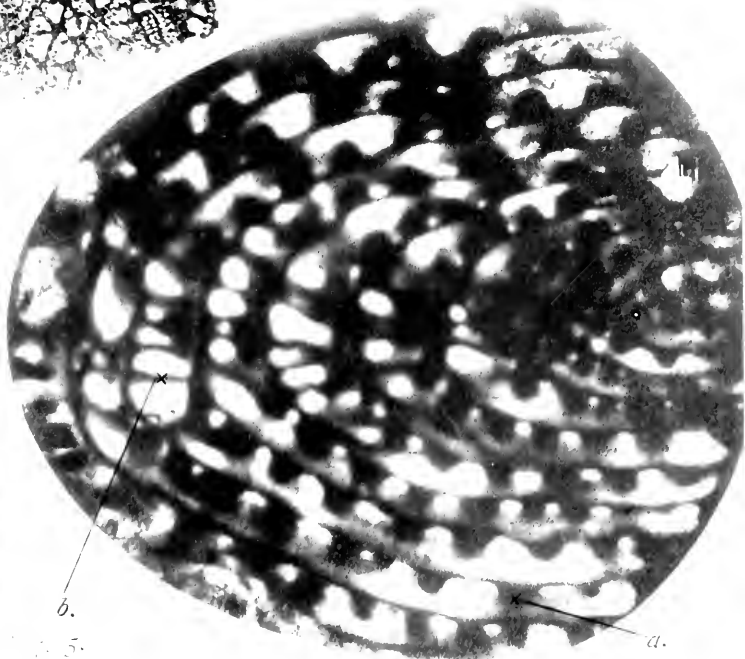


Fig. 3.



b.

Fig. 5.

a.



H. YABE.

A CONTRIBUTION TO THE GENUS *FUSULINA*.

PLATE III.

Reference to Plate III.

- Fig. 1. *Neoschwagerina globosa* YABE, from Akasaka, prov. Mino. Tangential section. $\times 20$. a and d, transverse septa ; b, primary septa ; c, auxiliary septa.
- Fig. 2. *Schwagerina Verbeeki* GEINITZ var., from U-chai, prov. Yun-nan, China. Cross section. $\times 20$.
- Fig. 3. *Neoschwagerina craticulifera* SCHWAGER, from Sakawa, prov. Tosa, Japan. Tangential section. $\times 48$. Drawn from a photograph. Notice the outer layer of the shell and median lamellae of septa stained to yellowish brown.
- Fig. 4. *Fusulina* aff. *Richthofeni* SCHWAGER, from Phyong-yang, Korea. Tangential-section. $\times 48$.
- Fig. 5. Ditto. Cross section. $\times 48$.
- Fig. 6. *Stachia* sp. indet., from Phyong-yang, Korea. Longitudinal section. $\times 48$. Drawn from a photograph.

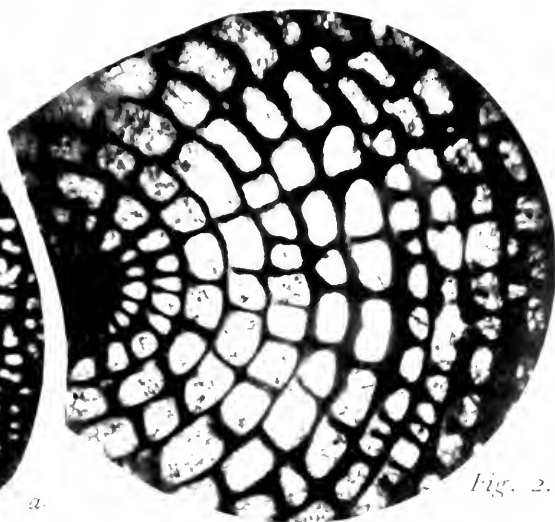


Fig. 4.



Fig. 6.

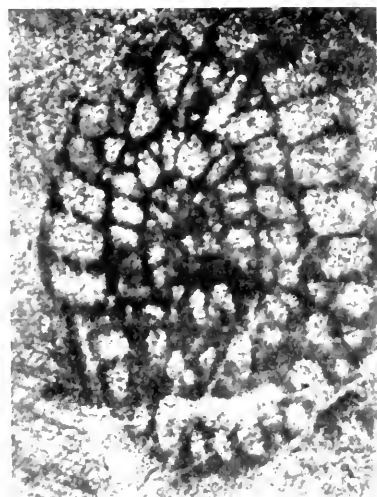


Fig. 5.



Hydroxylamine- α,β -Disulphonates (Structural Isomerides of Hydroximinisulphates or Hydroxylamine- β,β -Disulphonates).

By

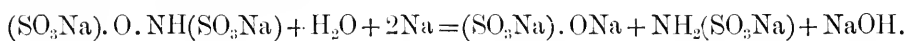
Tamemasa Haga, *Rigakuhakushi*.

Professor of Chemistry, Imperial University, Tōkyō.

In a previous paper (this Journ. **19**, Art. 15), it was shown that Fremy's *metasulphazilate*, which till then had been considered to be constituted as an amine oxide, $O : N(SO_3K)_3$, is in reality a *hydroxylaminetrisulphonate*. The nature of the products of the proximate hydrolysis of the metasulphazilates seems to afford the strongest additional evidence that these salts are hydroxylaminesulphonates and, as such, mixed anhydrides of an acid-sulphate and a hydroxylaminedisulphonate.

The ultimate hydrolysis of a hydroxylaminetrisulphonate, through intermediate stages, into hydroxylamine and an acid sulphate, is difficult to carry to completion (this Journ. **19**, Art. 15, 28), but the first stage of it, into a hydroxylaminedisulphonate and one-third of the quantity of acid-sulphate that is produced in the ultimate hydrolysis, is very easily accomplished. The hydroxylaminedisulphonate thus obtained proves to be an entirely new salt, structurally isomeric with the corresponding *hydroxylaminedisulphonate* (Fremy's *sulphazotate*), from which it differs greatly in

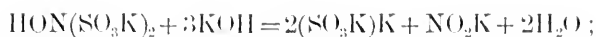
essential physical and chemical properties. The one is a $\beta\beta$ -derivative, the other an $\alpha\beta$ -derivative of hydroxylamine. Which is which is determined by the behaviour of the two salts towards sodium amalgam. A salt of the series already known remains unaffected, whilst one of the new series decomposes (p. 12) into sulphate and aminemonosulphonate (sulphamate, aminosulphate), just as its parent salt, hydroxylaminetrisulphonate, decomposes, in like circumstances, into sulphate and aminedisulphonate (iminosulphate). It must, therefore, have the $\alpha\beta$ -constitution, as shown in the following equation, framed to express its decomposition by sodium :



and the other salt have the $\beta\beta$ -constitution which it has always been assumed to have, $\text{HON}(\text{SO}_3\text{Na})_2$. The activity of the $\alpha\beta$ -salts towards sodium amalgam serves also to demonstrate their sulphatic constitution (derived from that of the hydroxylaminetrisulphonates) as the mixed anhydrides* of an acid-sulphate and a hydroxylaminemonosulphonate.

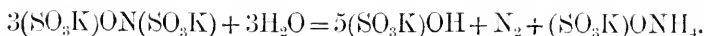
The action of potassium hydroxide upon the two salts seems clearly to establish the difference there is in their constitution. The old salt reverts to nitrite and sulphite when it is left, even in the cold, in a concentrated solution of the alkali (this Journ. 7, 40), whereas the new salt is only incompletely decomposed into sulphate, aminemonosulphonate, and nitrogen (p. 13), after several hours' digestion at 100–125° with the alkali. These results are exhibited by the following equations, the upper for the old or $\beta\beta$ -salt and the lower for the new or $\alpha\beta$ -salt :

* Two other examples of such mixed sulphatic anhydrides are any hydroxylaminetrisulphonate and any hyponitrososulphate. Raschig has recently adduced evidence (*Zeitung. Chem.*, 1905, 18, 1309) that nitrosyl sulphate is, after all, not a sulphate but a nitrosulphonate, $\text{O}_2\text{N}.\text{SO}_3\text{H}$.



The lower of these equations recalls the action of heated alkalis upon hydroxylamine (Lossen) and upon hydroxylaminemonosulphonate (Claus). The upper equation brings out strongly the oximide constitution of the $\beta\beta$ -salt.

It is an interesting fact that the course of the hydrolysis of the two salts in acidified solution is widely different, but it is a fact which cannot apparently be used to establish the nature of the difference in their constitution. The $\beta\beta$ -or long-known salt, by losing one of its two sulphonate groups, readily passes into the hydroxylamine- β -monosulphonate, $\text{HONH}(\text{SO}_3\text{K})$, whereas the new or $\alpha\beta$ -disulphonate passes (p. 15), much less easily, into acid sulphate and hydroxylamine itself (and products of its well-known decomposition), without ever affording evidence of any production of a monosulphonate, which in this case should have the α -constitution, expressed by $(\text{SO}_3\text{K})\text{ONH}_2$, and, as an amidogenium salt, be perhaps incapable of existence. The slowness with which an $\alpha\beta$ -salt begins to hydrolyse is illustrated by the fact that a solution of the potassium salt will remain clear for five minutes at the common temperature after it has been mixed with hydrochloric acid and barium chloride, whereas a solution of the $\beta\beta$ -salt will almost at once begin to show turbidity. When the hydrolysis of the $\alpha\beta$ -salt proceeds in the absence of much or any hydrochloric acid, nitrogen and ammonia very largely take the place of the hydroxylamine which is obtained in nearly the theoretical quantity when the salt hydrolyses in presence of a sufficiently concentrated hydrochloric-acid solution. The following equation expresses what principally happens in the absence of hydrochloric acid:



Silver oxide and lead peroxide seem to be without action upon the $\alpha\beta$ -salts in solution; they certainly do not produce the deeply coloured peroxyaminesulphonate which so strikingly results from their action upon the $\beta\beta$ -salts. This difference accords with that indicated in the constitution of the two series of salts. A hydroxylamine- $\alpha\beta$ -disulphonate also unexpectedly agrees with a hydroxylamine- $\beta\beta$ -disulphonate in not reducing copper or silver oxide in alkaline solution and is also inactive upon a solution of iodine in presence of sodium acid-carbonate. A hydroxylaminemonosulphonate, $\text{HONH}(\text{SO}_3\text{K})$, which, like it, has an aminic hydrogen atom in its constitution has the activity of hydroxylamine upon both alkaline copper solution and upon alkali-bicarbonate iodine solution.

Like the $\beta\beta$ -salts the hydroxylamine- $\alpha\beta$ -disulphonates decompose with gentle explosion when heated. Also, like the $\beta\beta$ -series, that of the $\alpha\beta$ -disulphonates includes highly alkaline normal salts, such as $(\text{SO}_3\text{K})\text{ONK}(\text{SO}_3\text{K})$ and $(\text{SO}_3\text{Na})\text{ONNa}(\text{SO}_3\text{Na})$.

A concentrated solution of the disodium salt is not precipitated by silver nitrate, mercuric nitrate, lead nitrate, or barium chloride. A concentrated solution of basic lead acetate precipitates from it an oil, which becomes crystalline on standing. A concentrated solution of a potassium salt precipitates from it the very much less soluble potassium salt. Barium hydroxide gives a voluminous, apparently amorphous, precipitate, probably of a sodium barium salt.

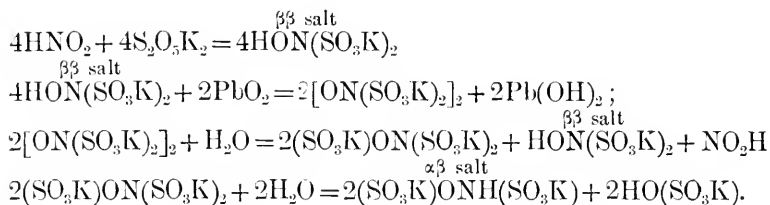
The molecular magnitude of the normal or trisodium hydroxylamine- $\alpha\beta$ -disulphonate. (p. 11), as determined cryoscopically by means of melted Glauber's salt (Löwenherz), is that expressed by $\text{O}_7\text{NS}_2\text{Na}_3$, the same, therefore, as that found for the normal

sodium β,β -salt (this Journ. **19**, Art. 15, 33). Remarkably, however (and it is a unique experience with this method, so far as has been ascertainable), the depression of the solidifying point of the sodium sulphate is at first much less than that which corresponds with the simple molecular weight, the number for which it only reaches and remains steady at, in the course of an hour or two and after several repetitions of remelting and solidifying. It would seem from this that the solid salt consists of associated simple molecules which require time to separate from each other after dissolution in melted Glauber's salt.

The discovery of this new series of salts, establishing as it does the existence of significant structural isomerism in other than carbon compounds, should prove to be of very special interest, there being hardly any other instance known, except that of nitramine with hyponitrous acid, the existence of which is disputed by Hantzsch (*Zeit. anorg. Chem.*, 1898, **19**, 106) just because it would be the only case known in inorganic chemistry.

The subjoined scheme of equations may serve to show at a glance the relation by derivation of the new series of salts to the old series. A hydroxylamine- β,β -disulphonate, a salt formed by the union of nitrous acid with a metasulphite, is oxidisable wholly into a peroxyamine-sulphonate. This, by hydrolysis in presence of an alkali, becomes, to the extent of half its nitrogen, hydroxylaminetrisulphonate; to the extent of a fourth of its nitrogen, the β,β -salt again; and, to the extent of the remaining fourth of its nitrogen, nitrous acid (nitrite) again. Lastly, by acid hydrolysis, the hydroxylaminetrisulphonate becomes sulphate and a hydroxylamine- α,β -disulphonate. From this it will be seen that, at most, only the half of the β,β -salt comes out as the α,β -salt,

one-fourth of it being regenerated and the remaining fourth reverting to its parent salts, of which the sulphite has suffered oxidation to sulphate.



The return of an $\alpha\beta$ -salt to the state of its $\beta\beta$ -isomeride can hardly be looked upon as possible, its own production having been due to oxidation of a fourth of the sulphonate groups into acid-sulphate.

Salts

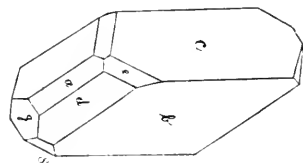
Dipotassium Hydroxylamine- $\alpha\beta$ -disulphonate, — $(\text{SO}_3\text{K})\text{ONH}(\text{SO}_3\text{K})$.—Potassium hydroxylaminetrisulphonate, dissolved in ten times its weight of warm water (it is much less soluble in cold water, this Journ. **19**, Art. 15, 8), soon begins to hydrolyse when its solution is quickly cooled and mixed with a drop of dilute sulphuric acid just before it would otherwise crystallise out again. The hydrolysis, to the end of its first stage, is complete in about four days. When the solution is deprived of sulphate and neutralised by the addition of barium carbonate or hydroxide, filtered, and evaporated, the new disulphonate is obtained in crystals, to the extent of at least two-thirds of the calculated yield. That hydrolysis of the trisulphonate proceeds to the extent shown in the equation (see above) in about four days and then proceeds much more slowly, has been ascertained both acidimetrically and by estimation of the sulphuric acid produced.

The dipotassium salt is an anhydrous salt, about twice as

soluble in water as the corresponding (but hydrated) $\beta\beta$ -salt. Of it 6.44 parts at 16.4° , 7.18 parts at 17.8° , and 8.05 parts at 20° dissolve in 100 parts of water. Its solution is neutral to litmus, to methyl-orange, and to phenolphthalein.

The salt forms hard monoclinic prisms which are sometimes short thick prisms, sometimes flattened tables, and sometimes long slender prisms or needles. Crystals of the one or other habit generally recrystallise in that habit but the salt is not dimorphous. A saturated solution of one form of the salt is saturated also towards another form of it, whilst the two forms will lie side by side unchanged for a length of time in the same mother-liquor. Prof. Jimbō has kindly supplied the following account of his examination of a short thick prism:—A monoclinic crystal, developed perfectly on one end of the clinodiagonal, about 6 mm. long, was measured by means of a contact goniometer, only two angles, c e and e d , having been measured by reflection. The faces a and g were depressed; the other faces also did not give good images. Seven faces were recognised; one other could not be determined.

a.	$\infty P\infty$	bd	=	$133^\circ 25'$
b.	$\infty P\infty$	ce	=	$144^\circ 27'$
c.	$\circ P$	cf	=	$127^\circ 53'$
d.	∞P	ed	=	$141^\circ 25'$
e.	$-P$	df	=	$126^\circ 15'$
f.	$P(?)$	cg	=	117°
g.	$\frac{7}{4} P\infty(?)$			



The results of analyses, of (A) the tabular form and of (B) the acicular form of the salt, are as follows:

A.	.2863 gave .1845 potassium sulphate.	Potassium	=	28.98
	.2105 gave .3673 barium sulphate.	Sulphur	=	23.96

	.2739 gave 12.58cc moist nitrogen at	
	19.5° and 756.1mm.	Nitrogen = 5.22
B.	.2679 gave .1751 potassium sulphate.	Potassium = 28.74
	.2684 gave 11.9cc. moist nitrogen at	
	16.7° and 765.5mm.	Nitrogen = 5.19

$\text{HO}_7\text{NS}_2\text{K}_2$ requires potassium, 29.06; sulphur, 23.79; nitrogen, 5.21 per cent. In all analyses given in this paper sulphur was determined by heating the salt with hydrochloric acid in a sealed tube at 180 for five hours or at 200° for two hours.

Tripotassium Hydroxylamine- $\alpha\beta$ -disulphonate, $(\text{SO}_3\text{K})\text{ONK}(\text{SO}_3\text{K})_2\text{H}_2\text{O}$.—This salt is precipitated, at first as an oil, when alcohol is added to its concentrated aqueous solution, prepared by dissolving the disulphonate in a little hot water and adding to it the calculated quantity of potassium-hydroxide solution. The oily salt slowly solidifies into lumps of microscopic crystalline plates. The quantity obtained should be about equal in weight to that of the disulphonate used, the calculated quantity being five parts from four. It is very soluble in water. Its solution is not precipitated by barium chloride, in this respect being unlike a solution of the corresponding $\beta\beta$ -salt. It is caustic in taste, and explodes suddenly when heated.

Analysis: .1696 gave .1286 potassium sulphate. Potassium = 34.05
 .2588 gave .1944 potassium sulphate. Potassium = 33.73
 .1568 gave .2343 barium sulphate. Sulphur = 20.52

$\text{H}_4\text{O}_9\text{NS}_2\text{K}_3$ requires potassium, 34.18; sulphur, 18.66 per cent

The *disodium salt*, $(\text{SO}_3\text{Na})\text{ONH}(\text{SO}_3\text{Na})$, is like the $\beta\beta$ -salt, anhydrous. The very soluble sodium hydroxylaminetrisulphonate is dissolved in five times its weight of water and acidified with dilute sulphuric acid. In two or three days at the ordinary temperature it will have all hydrolysed and the solution is then

to be neutralised with sodium carbonate. On exposure for a night in the ice-chamber, almost all the sodium sulphate will crystallise out and then the mother-liquor can be evaporated to get the new salt. Like corresponding $\beta\beta$ -salt, this salt forms hard masses firmly adhering to the sides of the vessel. These masses are stellar or warty groups of microscopic thick rhombic plates. The salt is exceedingly soluble in water, from which it can be nearly all precipitated by alcohol. Two preparations of the salt were analysed (I. and II) :

I.	.2209 gave .1313 sodium sulphate.	Sodium	=	19.28
	.1059 gave .2096 barium sulphate.	Sulphur	=	27.17
	.5151 gave 26.45 cc. moist nitrogen			
	at 17° and 756.8mm.	Nitrogen	=	5.94
II.	.2509 gave .1502 sodium sulphate.	Sodium	=	19.41
	.0959 gave .1910 barium sulphate.	Sulphur	=	27.35
HO ₇ NS ₂ Na ₂ requires sodium, 19.43 ; sulphur, 27.02 ; nitrogen, 5.92 per cent.				

The *trisodium salt*, (SO₃Na)ONNa(SO₃Na),2H₂O, is prepared just in the same way as the tripotassium salt. It is obtained as a crystalline powder. For determination of its molecular magnitude, see p. 11.

.1450 gave .1054 sodium sulphate.	Sodium	=	23.57
.2269 required 7.56cc. N/10hydrochloric acid with methyl-orange as indicator.			
	Alkalinity as sodium	=	7.66
.3594 gave .5698 barium sulphate.	Sulphur	=	21.75
H ₄ O ₉ NS ₂ Na ₃ requires sodium, 23.41 ; alkalinity sodium, 7.8 ; sulphur, 21.71 per cent.			

Diammonium salt, (SO₃NH)ONH(SO₃NH₂).—Ammonium hydroxylaminetrisulphonate (this Journ. 19, Art. 15, 9 hydrolyses

in the same way as the sodium salt. The ammonium acid-sulphate is got rid of by adding just enough barium hydroxide solution, filtering, and evaporating, at first at a gentle heat and then in the cold over sulphuric acid under reduced pressure. It occurs as small thick plates, which are somewhat hard, and as nodules composed of minute tabular crystals. It is a very soluble salt, 3 parts dissolving normally in just 2 parts of water at 18° , but it is very apt to form supersaturated solutions. It is a more stable salt than the corresponding $\beta\beta$ -salt. Its crystals are probably anhydrous, but those analysed showed the presence of $0.25 \text{ H}_2\text{O}$ per molecule.

.3559 gave .7189 barium sulphate. Sulphur = 27.74

.2320 gave 35.5cc. moist nitrogen at

16.2° and 754.5mm. nitrogen = 18.18 per cent.

$\text{H}_9\text{O}_7\text{N}_3\text{S}_2$ requires sulphur, 28.21; nitrogen, 18.53. With $\frac{1}{4}\text{H}_2\text{O}$ added, it requires sulphur, 27.66; nitrogen 18.17 per cent.

Barium salts.—Barium salts have not been prepared in a state suited for satisfactory determination of their nature. Evaporation of a solution of the ammonium salt with excess of barium hydroxide in a vacuum over sulphuric acid to a small volume removed all ammonia. After removal of the excess of barium hydroxide by carbon dioxide, the filtered solution was further evaporated in the desiccator. First, a viscid liquid and then a bulky friable, porous mass, devoid of crystalline character, were obtained. The latter was not quantitatively analysed but it yielded, when hydrolysed, barium sulphate and hydroxylamine sulphate in crystals which were further identified by a very satisfactory sulphuric acid determination. The product was therefore undoubtedly a barium hydroxylamine- $\alpha\beta$ -disulphonate. By using less barium hydroxide, crystallised ammonium barium salts of varying composition may

be obtained. One quantitatively examined had a composition corresponding fairly well with that of a compound of 6 mol. of the diammonium salt with 1 mol. of the $\frac{2}{3}$ -normal barium salt.

Molecular Magnitude of Trisodium Hydroxylamine- α,β -disulphonate.

By Löwenherz's method, the molecular magnitude of the trisodium hydroxylamine- β,β -disulphonate has been found to be (anhydrous) 233 and 239.6, whilst $\text{O}_7\text{NS}_2\text{Na}_3$ requires 259.35 (this Journ. 19, Art. 15, 33). By the same method, the following approximations to the same number have been obtained for the α,β -salt, namely, 269.6, 279.3, and 256.4, using the constant, 32.6, for sodium sulphate found by Löwenherz. The details of these determinations of the molecular magnitude of the α,β -salt are specially interesting (p. 4). Of this salt, .8371, dissolved in 40.48 melted Glauber's salt, produced a depression of 0.22° in the crystallising point, corresponding with the mol. weight, 306.2. After solidifying and melting three times, the depression reached 0.24° and remained at that, which corresponds with 269.6. There was now added .5848 more of the salt, and the depression due to this addition was at first only $.005^\circ$, corresponding with a mol. weight of 9416, that is, about 40 times the normal magnitude. On allowing the mixture to solidify and remelt, the depression grew in amount until at the sixth repetition it reached its maximum, corresponding with the simplest formula of the salt. The whole quantity, 1.4219 now caused a depression which gave the mol. magnitude as 279.3. Adding now .9026, the additional depression was at first only $.04^\circ$, corresponding with a mol. weight of 1878 which is about 8 times the simple molecule. But, again as

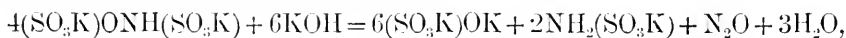
before, after several times repeated melting and solidifying, the normal depression was reached and remained constant, and the total quantity of the salt, namely, 2.3245 gave a depression of 0.73° , indicating the molecular magnitude, 256.4.

Reduction of the Disodium Salt by Sodium Amalgam.

Disodium hydroxylamine- $\alpha\beta$ -disulphonate, .4811 gram, was shaken with 12 grams of 3 per cent. sodium amalgam (which acts very slowly on it) and left with it, with occasional shaking, for three days. Much sodium remained unconsumed. The solution was rendered neutral to phenolphthalein by acetic acid and the sulphate present precipitated as barium sulphate. Of the sulphur in the quantity of salt taken, 13.73 per cent. were thus found as sulphate, instead of 13.51, the calculated third. The aminemonosulphonate in the filtrate from this sulphate was hydrolysed by heating the solution at 150° for three hours in a sealed tube with hydrochloric acid. It thus yielded the rest of the sulphur as sulphate, a result which, effected at such a temperature, showed that that sulphur was all in direct union with nitrogen and that none of the hydroxylaminedisulphonate had been left undecomposed by the sodium. As a check, the ammonia, the other product of the hydrolysis of the aminemonosulphonate, was also determined and found equal to 5.5 per cent. instead of 5.94 per cent., the full amount. The production of aminemonosulphonate by the reduction of the hydroxylamine- $\alpha\beta$ -disulphonate was further established quantitatively in a separate experiment, in which, after the reduction, the aminesulphonate was precipitated characteristically by mercuric nitrate and the acid itself, after recovery from its mercury salt, crystallised out and otherwise tested.

*Decomposition of the Potassium Salt by
Potassium Hydroxide.*

Whether potassium hydroxylamine- $\alpha\beta$ -disulphonate is decomposed solely into acid-sulphate, aminemonosulphonate, and nitrogen, when heated with a concentrated solution of potassium hydroxide (p. 3), or whether it is, to a small extent, decomposed into nitrous oxide, according to the equation,—



is not certain. It is experimentally difficult to get sufficiently trustworthy qualitative results. Even qualitatively, there is the uncertainty to deal with, as to the entire absence of nitrous oxide from the nitrogen obtained. In these experiments, the gas given off extinguished a flaming match and refused when mixed with hydrogen to explode by the electric spark. The occasional production of some nitrous oxide is, perhaps, to be inferred from the ratio of the quantity of sulphur as sulphate to that as aminemonosulphonate found in one experiment, although its production was not thus indicated in another experiment. But, as accuracy in determining this ratio is affected by the fact that the analytic separation of sulphate from aminemonosulphonate is only approximate (this Journ. 9, 281–2; 13, 503–6), the production of any nitrous oxide still remains uncertain. Another difficulty in the quantitative examination of the decomposition is that the decomposition is far from complete after several hours heating at 120° . The presence of still undecomposed salt is shown by the production of hydroxylamine when the products are hydrolysed and by the fact that a temperature of 180° , instead of 150° , is necessary to ensure complete hydrolysis of the products.

No ammonia is generated, the only products being those already mentioned.

When the gases were to be collected the salt was heated with one and a half to twice its weight of potassium hydroxide and about four times its weight of water for six hours at 100° or for four hours at 120° in a tube retort connected with a Sprengel pump. Needless to say, explosive ebullition and corrosion of the hard glass tube (rendering it opaque) had to be encountered as difficulties. When the gases were to be allowed to escape, the mixture was heated in a platinum dish on the water bath. For analysis, the residue in either case was made faintly acid to phenolphthalein by nitric acid, and sulphate then precipitated by barium nitrate. The thoroughly washed precipitate was purified in the usual way by fusion with an alkali carbonate before weighing. The aminesulphonate was precipitated by mercuric nitrate, the mercuric salt was hydrolysed, and the sulphuric acid and sometimes the ammonia resulting were determined. The filtrate from the mercury precipitate always showed the presence of hydroxylamine- $\alpha\beta$ -disulphonate.

In an experiment with 1.057 gram of salt, the sulphur found as sulphate was 66.82 per cent., and that as aminesulphonate 15.73 per cent. of the total sulphur, leaving 17.45 to be accounted for as undecomposed salt. Of the total nitrogen, 29.64 per cent. were got as ammonia from the aminesulphonate, and 48.89 per cent. as gas (27.85 cc. moist nitrogen at 18° and 639.8 mm. = .002692), leaving 21.47 per cent. as undecomposed salt. The difference between 17.45 and 21.47, perhaps due to slight leakage of air into the apparatus during the six hours heating, is not at all so significant as it is made to appear by the way of stating the results, the total percentage of nitrogen in the salt being only

5.2 per cent. On the assumption that 65 per cent. of the salt decomposed so as to give nitrogen (p. 3), and 16.7 so as to give nitrous oxide (p. 13), and that 18.3 per cent. remained undecomposed, the numbers should be sulphur as sulphate, 66.68, and as aminesulphonate, 15.01 per cent., nitrogen as aminesulphonate, 30.02, and as free nitrogen and nitrous oxide, 48.30 per cent., of the total.

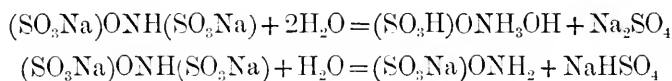
In another experiment, in which .9792 salt was heated at 120–125° for four hours, the indications of the analysis were that 19.9 per cent. of the salt had resisted decomposition and that no nitrous oxide had been formed. The numbers obtained were 66.69 per cent. sulphur as sulphate, instead of 66.75 calculated; and 12.94 sulphur as aminesulphonate, instead of 13.35 calculated. Some of the gas was lost, so that the distribution of the nitrogen could not be sufficiently tested.

In an experiment, in which the salt was heated at 100° with potassium hydroxide for many hours in a platinum dish with occasional renewal of the water, the sulphur of the sulphate produced amounted to 77.24 per cent. of the total. Decomposition of all the salt with production of nitrogen would give 83.33 per cent.

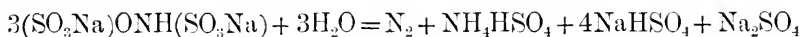
Products of Hydrolysis of Hydroxylamine- α , β -disulphonates.

Potassium hydroxylaminetrisulphonate, which for these experiments could be substituted for the disulphonate, the product of its hydrolysis, was moistened with dilute sulphuric acid and heated in a vacuum at 100°, in order to effect its hydrolysis and collect the gas evolved. The gas had no action upon ferrous sulphate, and was not appreciably soluble in alcohol. It therefore contained no nitric oxide and apparently no nitrous oxide.

Sodium hydroxylaminetrisulphonate in solution in water, just acid with sulphuric acid, was left for several days to slowly hydrolyse, principally to the disulphonate. It was then kept for fifty minutes at 95°, during which brisk effervescence of nitrogen went on, slackening only when near the end of the time. The acidity was then found to be somewhat more than that indicated by either of the following equations, the one for hydroxylamine sulphate, the other for the unknown hydroxylamine- α -monosulphonate :



The additional acidity and the escape of nitrogen indicated the occurrence, to some extent, of the decomposition expressed by:—



The solution gave only a moderate reaction for hydroxylamine with the copper test, and on evaporation, with or without previous neutralisation, gave nothing but sodium and ammonium sulphates.

In presence of sufficient hydrochloric acid, say, one volume of the fuming solution to ten volumes of solution of the salt, the production during hydrolysis of nitrogen and ammonia is very slight. The disodium salt in such a solution, after it had been kept heated for five minutes or so by immersing the vessel in boiling water, gave evidence, on titrating with iodine, of the presence of hydroxylamine equivalent to 9.5 per cent. of the salt. In another experiment, in which the solution was left standing for 50 days at the ordinary temperature, 76.5 per cent. of the salt had then yielded hydroxylamine.

In another similar experiment, the solution after standing in the cold was also evaporated in the cold under reduced pressure, until the salts crystallised out, and still nothing else but sodium

and hydroxylamine sulphates, except a very little ammonium sulphate, was obtained.

In other experiments, using in these cases the dipotassium salt, the hydrolysis was allowed to go on either in the cold or at 60°, and portions of the solution occasionally tested to see whether some indication could be got of the production of hydroxylamine- α -monosulphonate at any stage of the hydrolysis. In making the test, the acid sulphate was removed by barium chloride and the solution then tested with iodine in presence of sodium acid-carbonate. Since the consumption of the iodine caused no precipitation of barium sulphate, evidence was thus obtained that the reducing substance was hydroxylamine only and not its sulphonate derivative. Ultimately, by evaporating the solution, when sufficiently hydrolysed, hydroxylamine sulphate was crystallised out, along with the sodium sulphate.



On the Effect of Stress on Magnetization and its Reciprocal Relations to the Change of Elastic Constants by Magnetization.

By

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With 5 plates.

In our previous experiments, we investigated in some detail the change of elastic constants of several ferromagnetic metals and alloys caused by magnetization, with special regard to the order of applying the stress and the field, and found that in some cases, the change is considerably large and moreover that it differs more or less for different orders of applying the stress and the field. In order to find the proper explanation of these facts, it will be necessary to investigate with the same specimens as in the previous experiment, the change of magnetization by stress, with special regard to the order of applying the stress and the field.

Since J. J. Thomson¹⁾ gave his theoretical exposition of the reciprocal relations between magnetism and strain, several theories²⁾

1) J. J. Thomson, Application of Dynamics to Physics and Chemistry, Chapter IV.

2) F. Koláček, Ann. d. Phys., **13**, p. 1, 1904; Ann. d. Phys., **14**, p. 177, 1904. A. Heydweiller, Ann. d. Phys., **14**, p. 602, 1903. R. Gans, Ann. d. Phys., **13**, p. 634, 1904. S. Sano, Proc. Tōkyō Math.-Phys. Soc., **2**, p. 175 and 207, 1904.

in the same field have been published, and the present investigation may also afford interesting materials for testing the validity of these theories. In this direction, we have been preceded by Rensing¹⁾ and Cantone,²⁾ in the case of iron and nickel; but, a more extended researches, may not be undesirable. With this view, sets of experiments have been undertaken firstly to investigate the change of magnetization by applying successive stresses under constant fields; and secondly, to investigate the magnetization by applying the magnetizing field under different constant stresses and thence to deduce indirectly the change of magnetization by stresses.

Specimens used had the following dimensions:—

Specimens.	Length.	Diameter.	Demagnetizing factor.
Swedish iron.	21.30 cm.	0.903 mm.	0.00089
Tungsten steel.	26.85	0.885	0.00050
Nickel.	26.87	0.863	0.00056
28.74 % Ni.	26.80	0.964	0.00063
50.72 % Ni.	27.00	0.880	0.00050
70.32 % Ni.	26.86	0.891	0.00068

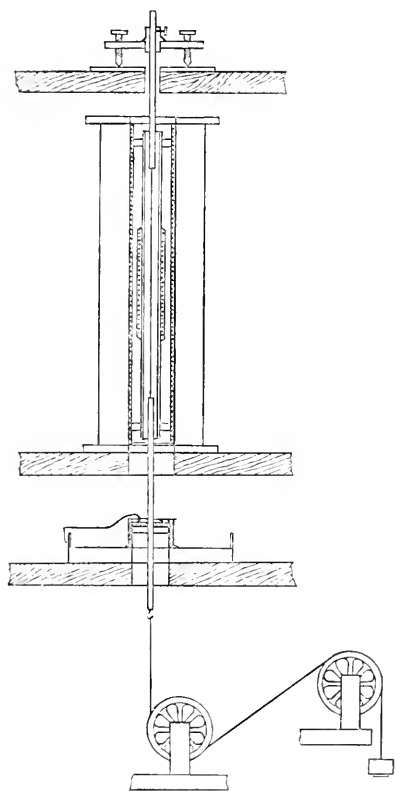
§ 1. APPARATUS.

The intensity of magnetization was measured by the ballistic method; this method was preferred to the magnetometric one, since in our experiments, fields up to 400 C.G.S. units were required, and consequently the adjustment of a very sensitive magnetometer placed close to a pair of compensating coils traversed by a strong current would be extremely troublesome. The

1) Rensing, *Ann. d. Phys.*, **14**, p. 363, 1904.

2) Cantone, *Rend. d. Ist. Lomb.*, (2) **37**, p. 435, 1904. *Ibid.* p. 474, 535 and 567.

magnetizing coil which was one that had been used in our previous experiments, was placed in its vertical position. The length and the constant of the coil were respectively 40 cm. and 392.6. A secondary coil was wound on a glass tube (external diameter 1.5 cm.), consisting of 1246 turns of well insulated copper wire (diameter=0.56 mm.) in 6 layers, the length of the coil being 14 cm. This secondary coil was fixed coaxially in the magnetizing coil, so that the former might lie in a uniform field excited by the latter.



To compensate for the induction due to the magnetizing field alone, a similar secondary coil connected in series with the above secondary coil was inserted within another coil equal to and connected in series with the magnetizing coil, so that by sliding the secondary within the primary, the induction could be compensated to any desired degree. These two pairs of coils were placed at a sufficient distance from each other to prevent their mutual action. The ballistic galvanometer for measuring the induced current due to the magnetization of the specimen was drum-shaped, with 0.8Ω resistance; a mirror with a small magnet was

suspended in the center of the coil by a spider thread. Its period of oscillation was about 9 seconds. The galvanometer was

connected with the secondary circuit of the system and placed at a distance of about 15 meters from the magnetizing coil to avoid their direct action. The galvanometer was, however, still disturbed, when a strong current was switched on to the magnetizing coil. To prevent this, the compensating primary was so directed that the direct effect of the combined system on the galvanometer was null. To determine the constant of the galvanometer, we should have used the compensating secondary coil, if it had been wound in one layer, so that its effective sectional area could be determined with sufficient accuracy. But, as the ambiguity of the sectional area in the secondary coil of 6 layers was inevitable, another coil was constructed with a thin copper wire wound on a wooden cylinder of 5.04 cm. diameter, in a single layer; the number of turns of the coil was 48. This was always put in series with the secondary circuit and placed at a sufficient distance to be safe from any sensible influence of the magnetizing circuit during the experiments for magnetization. When the constant of the galvanometer was to be determined, the compensating secondary coil was removed from the primary coil and replaced by this coil; then the magnetizing coil for the specimen was shunted off, a weak magnetizing current of known strength switched on to the primary coil, and the consequent deflection of the galvanometer was measured. The constant of the galvanometer was thus determined from the field in the primary coil and the dimensions of the secondary circuit in the usual manner. The resistance of the whole secondary circuit was 10.80 Ω .

The deflection of the galvanometer was read by means of a scale and telescope with a scale distance of 1.527 m. The sensibility of the arrangement was such that one scale division corresponded to a change of 1.42 C.G.S. units of intensity of magneti-

zation. To obtain a smooth motion of the galvanometer mirror due to the induction, it was found necessary that the two primaries as well as the two secondaries should have nearly the same dimensions respectively; the kick, which was observed when the dimensions of these coils were different, was probably due to the self-inductions and the capacities in these coils.

Compensation for the earth field was effected by a special coil of fine copper wire wound on a glass tube in a single layer. This coil fitted closely to the inside of the magnetizing coil and to the outside of the secondary. It was fed by a current from 2 Daniel cells with adjustable resistance in the circuit.

The current in the primary circuit was measured by a Siemens and Halske ammeter with two shunts, $\frac{1}{9}$ and $\frac{1}{99}$. This was occasionally compared with a Kelvin's ampere-balance.

The specimen to be tested was cut to a suitable length (about 27 cm.) so that if placed centrally, it might lie in a nearly uniform field of the magnetizing coil; it was brazed at its both ends to thick rods of brass. The whole was hung vertically in the axial line of the magnetizing coil, and consequently of the secondary coil, the upper rod being firmly clamped to the rigid frame above the coils. To the end of the lower rod, a hook was attached; from this hung a flexible cord which, after passing through a system of two pulleys, was stretched by a weight, without imparting any injurious pendulum motion to the specimen. Near the end of the lower rod, a rigid pin was screwed on perpendicular to the rod. The ends of the pin fitted to the two V-shaped grooves cut lengthwise and diametrically opposite to each other on the inside of a brass cylinder, which could be turned about a fixed vertical axis to any desired angle. The angle of twist was read by means of a graduated circle and the index attached to

the torsion cylinder to $\frac{1}{20}$ of a degree. In the experiment of the tension effect, the above arrangement served to prevent any accidental twisting of the specimen without causing a sensible friction to the stretching.

§ 2. METHOD OF EXPERIMENTS.

Our procedure was usually made in the following order: The direct effect of the magnetizing coil on the galvanometer was tested first of all. The specimen was removed, the secondary circuit opened, and the maximum current was passed through the primary. If there were any constant deflection of the galvanometer mirror, the observer signalled to the experimenter who adjusted the orientation of the compensating primary coil, till the deflection was brought to zero, in breaking, making or reversing the current.

Next the secondary circuit was closed, a strong current was passed through the primary, while the observer was watching the galvanometer; the compensating secondary was slid within the primary, till the ballistic deflection was reduced to zero.

Next the compensation for the earth field was effected. For this purpose, the specimen was introduced into the magnetizing coil, clamped firmly and stretched by a suitable tension, care being paid to place the wire co-axially with the coils. The specimen was carefully demagnetized by reversals; the secondary was closed, a weak field excited in the primary, and the consequent deflections noted. After a complete demagnetization, the same magnetizing current was passed in the opposite direction. If the two corresponding deflections of the galvanometer were not equal to each other, the resistance in the compensating circuit was so

adjusted, that the reversal of the magnetizing field, if it was repeated two or three times, caused an equal deflection of the galvanometer. This method was found to be very sensitive, a very small change of the current in the compensating system producing a decided inequality of the galvanometer deflections in opposite directions.

The tension effect was first tried. To wipe out any uncertain remanent stress of the specimen, cycles of tensions, from zero to the greatest to be used for the specimen, were passed through before commencing any experiment. As a preliminary to test the working of the arrangement, a series of increasing fields was applied step by step under a constant tension, and the increase of magnetization was observed by the galvanometer. After a complete demagnetization, a weak field was applied and kept constant. While the observer was watching the galvanometer, the experimenter applied a series of increasing tensions step by step; the throw of the galvanometer at each step was recorded. Then the tension was decreased step by step, and the corresponding deflection were sometimes noted. After passing through several cycles of the tensions, the observation was repeated. After a complete demagnetization, the procedure was repeated for another higher field and so on. The number of fields chosen was naturally large for the region where the change of magnetization was considerable, but rare where it was small. The magnetizing current was found to remain nearly constant during an experiment, except in strong fields, where it was sometimes found to vary 2 or 3 per cent. The reading of the ammeter was always observed both before and after the experiment, and the mean was taken.

Instead of increasing the tension step by step, the maximum tension was often applied at once; but it was found that the

consequent deflection of the galvanometer was nearly the same as the sum of the deflections obtained by the application of tension in successive steps.

Another series of experiments is possible in this direction. The specimen was demagnetized with the smallest initial tension; it was then magnetized, and then the deflection of the galvanometer due to an additional weight was observed. After several alternate additions and removals of the additional weight, the changes of magnetization due to the addition and removal were observed. Then the demagnetization with the initial and added weights was effected, and the change of magnetization due to a second additional weight was measured, and so on.

Next the magnetization under constant tension was determined. The specimen was first thoroughly demagnetized by reversals, loaded with the empty pan only. A series of successively increasing fields was applied step by step, and the throw of the galvanometer corresponding to each increment of the field was recorded. Demagnetization was again effected, after the specimen had been loaded with an additional tension, and the magnetization tested in the same way; and so on. In this way, the magnetization under different constant tensions was obtained.

The procedure in the experiments on the effect of torsion was similar. The torsion was increased step by step under a constant field and the change of magnetization corresponding to each step was observed. The effect of cyclic twist was also investigated. The effect of the maximum twist applied at once does not differ from the sum of the deflections obtained by a graduated applications of twists, as in the case of tension. The magnetization under constant torsions was next measured. These sets of experiments were repeated for several tensions nearly equal to

those used in our previous experiments on the change of rigidity by magnetization.

The standardization of the ballistic galvanometer was made for each set of observations, though the constant remained fairly constant during the whole experiment. Instead of using each time the special coil made for the standardization, we often used the compensating secondary coil for a set of experiments, recording the deflections of the galvanometer corresponding to a series of magnetizing currents, and at the end of a set, the induction of this coil was compared with the standardizing coil. In this way, time and labour were economized, without the risk of introducing any sensible error in the constant of galvanometer.

§ 3. RESULTS OF EXPERIMENTS.

The intensity of magnetization was calculated in the usual manner from the throw of the ballistic galvanometer with a known constant, the numbers of turns of the secondary and the standardizing coil, and the sections of the specimen wire and the standardizing coil. The necessary correction for the reduction to tangent was made for considerable deflections. The magnetizing field was calculated from the reading of the ammeter of known constant, by use of the known turns of the coil. The demagnetizing force, though it was very small, was also taken into account. Tensions were all reduced to weights per square millimeter, and torsions to twists per unit length.

In the following pages, I denotes the intensity of magnetization, H' the external field applied and H the internal or effective field, all expressed in C.G.S. units; T denotes the tension in grams per square millimeter, and τ the twist in minutes of arc per unit of length.

I. SWEDISH IRON and TUNGSTEN STEEL.

The effect¹⁾ of tension or of torsion on the magnetization of iron and steel is so well known that it is superfluous to enter into a detailed description of the effect. Only the general features of the change of magnetization will be given here. It will, however, be noticed that our investigation has one characteristic that several effects of the stress on magnetization were studied on the same specimen with special attention to the order of applying the stress and the field. The specimens were also those on which strains caused by magnetization had been fully studied; hence the numerical results of the present experiment should be of some use to theoreticians, who have either already obtained, or shall attempt to obtain, some reciprocal relations between magnetization and stress, so that they will be given in their proper places.

(a) *Change of magnetization by tension under constant field*: $(\partial I, T)_H$.

As will be seen from Figs. 1 and 3, the change of magnetization ∂I_i due to the initial effect of loading increases up to a moderate field, and then decreases with it. In Swedish iron, curves $(\partial I_i, T)_H$ in weak fields initially bend upward, and after passing through an inflexion point, the curvature changes sign. As the field is increased, the point of inflexion approaches the origin; in strong fields, ∂I_i is very small, and the curve is nearly straight. In tungsten steel, curve $(\partial I_i, T)_H$ has a slight curvature for all fields.

In weak fields, the effect of removing the suspended weight is very small and slightly increases the magnetization. Subsequent loading causes an increase of magnetization; and unloading,

1) See Wiedemann's *Electricität*, 3, chap. 4; Ewing's *Magnetic Induction*, chap. 9; Winkelmann, *Handbuch der Physik*, Zweite Auflage, V.4, p. 301-307, 313-319.

a decrease. In strong fields, the initial and the cyclic effect of loading nearly coincide with each other. Curves $(\partial I_c, T)_H$ for cyclic effects are given in Figs. 2 and 4 in magnified scale. Curves $(\partial I_c, H)_T$ as deduced from the initial effect of $(\partial I_c, T)_H$ are given in full lines in Figs. 5, 6 and 7: they rise and then fall steeply in low field, and afterward decrease slowly, cutting the axis of H at the Villari points. The decrease of magnetization reaches a maximum, and then gradually diminishes tending to approach zero, as the field is increased. This maximum decrease had been anticipated from the theory of magnetostriction¹⁾ by Professor Nagaoka and one of us. Curves $(\partial I_c, H)_T$ as deduced from $(\partial I_c, T)_H$ of the cyclic effect rise only slightly in weak fields; but in strong fields, they nearly coincide with curves $(\partial I_c, H)_T$ for the initial effect. The following are the numbers obtained by experiments.

SWEDISH IRON.

Initial $T=152 \text{ gr./mm.}^2$; $t=16.5^\circ \text{ C.}$

H'	$T=1562 \text{ gr. } T=3086 \text{ gr. } T=4648 \text{ gr. } T=6211 \text{ gr. } T=7777 \text{ gr.}$									
	∂I_i	∂I_c	∂I_i	∂I_c	∂I_i	∂I_c	∂I_i	∂I_c	∂I_i	∂I_c
1.25	6.8	0.9	23.2	1.9	56.8	3.2	100.9	4.5	146.3	6.9
2.56	31.3	0.8	91.4	1.5	181.4	2.3	275.8	3.1	313.7	6.1
4.37	106.4	0.1	226.2	-0.2	326.9	-0.6	397.8	-1.0	414.0	-0.8
5.88	115.5	-1.1	197.8	-1.9	251.7	-2.8	285.9	-4.0	310.9	-5.0
7.75	68.7	-1.7	111.1	-3.4	140.9	-5.0	160.7	-6.7	171.6	-8.5
11.90	25.3	-2.6	40.7	-5.2	51.0	-7.9	57.3	-10.5	61.1	-13.2
24.18	1.5	-3.4	1.8	-6.7	1.1	-10.2	-0.1	-13.9	-1.9	-17.1
36.55	-2.7	-3.8	-5.1	-7.8	7.5	-11.6	-10.3	-15.5	-13.3	-19.0
97.1	-4.0		-7.8		-11.6		-14.7		-18.2	
204.7	-3.8		-7.3		-10.8		-14.4		-18.1	
366.6	-2.7		-5.1		-8.0		-10.6		-13.3	

1) Nagaoka and Honda, Jour. Sc. Coll., **13**, p. 69, 1900; Phil. Mag. **49**, p. 340, 1900.

TUNGSTEN STEEL.Initial $T=159 \text{ gr./mm.}^2$; $t=14.2^\circ \text{ C.}$

H'	$T=1625 \text{ gr./mm.}^2$		$T=4837 \text{ gr./mm.}^2$		$T=8092 \text{ gr./mm.}^2$	
	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e
4.08	0.4	0.2	2.6	0.4	6.5	0.7
10.63	3.2	0.6	13.0	1.8	27.7	3.2
15.70	9.1	1.0	42.1	4.2	98.4	8.1
19.34	40.0	2.6	142.3	6.7	244.9	11.9
23.85	35.3	2.0	98.3	6.1	149.1	10.9
32.16	16.2	1.6	43.6	4.5	67.6	7.9
43.36	6.9	1.2	21.0	3.4	32.8	5.6
98.4	0.4	0.4	1.9	0.4	3.1	0.1
210.0	-0.4	0.0	-1.6	-1.3	-2.6	-2.8
341.0	-0.3	-0.3	-1.5	-1.7	-2.8	-3.4

The effect of applying the maximum tension at once is nearly the same as the effect of the graduated applications of tensions. This will be seen by comparing the following figures with the corresponding ones in the foregoing table.

SWEDISH IRON.Initial $T=152 \text{ gr./mm.}^2$; $t=16.5^\circ \text{ C.}$

$T=1562 \text{ gr./mm.}^2$			$T=3086 \text{ gr./mm.}^2$			$T=4648 \text{ gr./mm.}^2$		
H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e
2.57	33.1	1.0	2.43	84.1	3.3	2.57	194.0	6.2
4.20	101.3	3.2	4.23	206.6	5.3	4.13	323.4	5.4
5.80	116.4	3.2	5.87	198.4	4.0	5.78	259.4	2.3
11.65	27.3	-0.4	11.70	43.7	2.3	11.57	52.7	-4.9
42.13	-2.8	-3.8	39.62	-4.5	-7.1	39.26	-7.4	-11.0

The change of magnetization by tension under different initial loadings, where the demagnetization was always effected with the initial load, is given in the following table. For an equal increment δT of T , δI_i decreases rapidly, as the initial T increases, whereas in the graduated applications of tension, δI_i increases nearly proportional to δT . The difference between these two values of δI_i is considerable.

SWEDISH IRON. $t = 16.5^\circ C.$

$T = 152 \text{ gr./mm.}^2;$ $\delta T = 1562 \text{ gr.}$			$T = 1677 \text{ gr./mm.}^2;$ $\delta T = 1561 \text{ gr.}$			$T = 3238 \text{ gr./mm.}^2;$ $\delta T = 1562 \text{ gr.}$		
H'	δI_i	δI_e	H'	δI_i	δI_e	H'	δI_i	δI_e
2.57	33.1	1.0	2.49	16.5	-0.9	2.43	9.0	-1.2
4.20	101.3	3.2	4.01	49.5	-0.7	4.08	33.1	-2.3
5.80	116.4	3.2	6.00	59.7	-0.3	5.88	36.2	-2.4
11.65	27.3	-0.4	11.59	13.7	-1.8	11.77	6.4	-2.9
42.13	-2.8	-3.8	39.55	-3.0	-3.7	39.66	-3.0	-4.1

TUNGSTEN STEEL. $t = 14.2^\circ C.$

$T = 159 \text{ gr./mm.}^2;$ $\delta T = 1625 \text{ gr.}$			$T = 1784 \text{ gr.,}$ $\delta T = 1626 \text{ gr.}$			$T = 4996 \text{ gr.,}$ $\delta T = 1626 \text{ gr.}$		
H'	δI_i	δI_e	H'	δI_i	δI_e	H'	δI_i	δI_e
10.63	3.2	—	6.78	1.8	0.3	6.74	1.5	0.3
15.70	9.1	—	14.68	7.7	0.6	14.51	7.9	0.2
19.28	40.0	—	18.45	29.1	2.5	19.44	43.6	1.5
23.85	35.3	—	25.95	22.2	2.2	26.96	14.5	1.5
43.40	6.9	—	38.45	5.6	1.5	38.68	5.8	1.2
98.4	0.4	—	95.3	0.9	-0.9	95.6	0.0	-0.2
210.0	-0.4	—	200.7	-0.4	-0.7	202.5	-0.4	-0.7
341.1	-0.3	—	337.1	-0.4	-0.7	351.5	-0.4	-0.6

(b) Magnetization under constant tensions: $(I, H)_t$.

The magnetization increases rather rapidly in low fields and gradually approaches saturation. The effect of tension is, in its general features, similar to that obtained from $(\partial I, T)_H$. With low tensions, the increase of magnetization is considerably less than the value of the initial effect obtained from the latter experiment, while with high tensions, the contrary is true. These facts will be seen in the following tables and curves $(\partial I, H)_T$ in dotted lines in Figs. 5 and 7.

SWEDISH IRON.

$$t=16.^\circ 5 \text{ C.}$$

$T=152 \text{ gr./mm.}^2$		$T=1714 \text{ gr./mm.}^2$		$T=7929 \text{ gr./mm.}^2$	
H	I	H	I	H	I
0.87	18.5	0.88	22.3	0.84	21.3
1.63	52.7	2.17	91.7	1.63	59.8
2.89	161.3	3.12	235.5	3.16	269.8
4.42	509	3.67	441.3	3.86	495.4
6.35	835	4.69	710	4.48	727
8.48	1000	6.44	946	6.57	982
13.60	1141	15.23	1180	13.51	1149
23.72	1229	24.10	1238	23.85	1213
35.60	1275	35.83	1280	35.88	1251
58.39	1328	58.39	1331	54.34	1300
127.3	1416	126.6	1419	124.8	1387
219.4	1493	197.4	1478	195.6	1448
319.2	1542	319.1	1547	296.8	1511
386.5	1569	383.0	1573	381.9	1547

TUNGSTEN STEEL.

$$t = 13.7^\circ \text{ C.}$$

$T = 159 \text{ gr./mm.}^2$		$T = 178.4 \text{ gr./mm.}^2$		$T = 4996 \text{ gr./mm.}^2$		$T = 8251 \text{ gr./mm.}^2$	
H	I	H	I	H	I	H	I
2.33	14.4	2.35	14.9	2.77	17.6	2.33	14.2
4.68	31.2	5.14	35.3	5.54	38.5	4.60	29.8
7.90	58.8	8.85	69.1	9.07	71.2	7.99	60.3
12.07	107.5	12.41	114.2	12.87	123.7	12.17	113.6
16.98	202.3	16.76	212.9	16.76	223.6	16.80	241.8
19.29	304.7	19.00	341.2	18.98	381.7	18.99	449.0
22.29	532	22.06	597	21.96	631	22.02	695
27.73	788	27.66	837	27.46	852	27.64	877
33.94	918	33.60	955	33.91	965	33.98	976
41.70	1005	42.33	1041	42.72	1045	42.68	1046
63.2	1115	63.6	1144	63.2	1137	63.2	1133
105.2	1207	105.2	1233	105.2	1223	105.6	1215
158.3	1265	158.4	1291	157.7	1279	158.5	1268
212.6	1308	212.7	1327	210.9	1311	211.6	1304
268.7	1328	269.1	1342	267.1	1339	268.7	1330
345.2	1354	346.3	1380	343.8	1364	343.8	1356

(c) *Change of magnetization by twist under different tensions : $(\partial I, \tau)_{H, T}$.*

In Swedish iron and tungsten steel, the curves $(\partial I, \tau)_{H, T}$ (Figs. 8, 10 and 12) are similar to those for $(\partial I, T)_H$ for the initial effect. In weak fields where the twisting considerably increases the magnetization, the effect of the first untwisting is very small

and slightly increases the magnetization. In Swedish iron, the cyclic effect of twisting (Fig. 9) under low tensions is always to diminish magnetization. In high tensions (Fig. 11), the effect has a singular character: for a small twist, the magnetization increases, but for a large twist, it is diminished. In tungsten steel, the cyclic effect of twist is similar to the cyclic effect of tension in Swedish iron, but in amount it is very small. Curves $(\partial I_i, H)_{\tau, T}$ as deduced from $(\partial I_i, \tau)_{H, T}$ are given in Figs. 13, 14 and 15 in full lines. They greatly resemble those for the tension effect, having points corresponding to the Villari points. With considerable twist, $(\partial I_e, H)_{\tau, T}$ (Figs. 13 and 14) is always negative. The experimental numbers are given in the table below:—

SWEDISH IRON.

$$T=152 \text{ gr./mm.}^2; t=15.06 \text{ C.}$$

$\tau=31.9'$			$\tau=42.9'$			$\tau=69.8'$		
H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e
1.34	7.0	-1.0	1.26	18.6	-1.7	1.22	36.8	-4.2
2.43	17.3	-2.5	2.47	39.4	-5.6	2.38	73.2	-11.2
4.12	44.3	-5.4	4.22	90.8	-11.2	4.24	114.7	-20.0
5.86	44.6	-5.6	5.73	84.7	-11.2	5.73	125.0	-21.4
7.79	27.0	-5.3	7.79	43.5	-11.3	7.87	46.7	-22.5
13.56	4.6	-4.4	13.60	2.8	-10.3	13.59	-8.3	-22.5
24.04	-0.7	-3.1	23.78	-4.2	-8.2	23.74	-14.1	-18.3
48.95	-1.3	-1.7	42.01	-3.9	-4.4	39.29	-10.3	-11.5
114.4	-0.3	-0.3	117.5	-1.1	-1.4	116.8	-2.5	-3.0
212.7	-0.0	-0.3	219.0	-0.0	-0.8	215.2	-1.4	-1.4
367.1	-0.1	-0.1	—	—	—	370.6	-0.4	-0.9

$$T = 3238 \text{ gr./mm.}^2, \quad t = 15.6^\circ \text{ C.}$$

$\tau = 14.6'$			$\tau = 30.2'$			$\tau = 58.5'$			$\tau = 87.8'$		
H'	∂I_i	∂I_c	H'	∂I_i	∂I_c	H'	∂I_i	∂I_c	H'	∂I_i	∂I_c
1.21	5.7	0.6	1.22	30.2	3.3	1.22	125.2	3.8	1.21	182.1	-17.1
2.42	22.4	2.1	2.61	116.8	6.4	2.54	296.0	-2.0	2.55	385.0	-32.2
4.02	73.7	3.7	4.05	194.0	5.7	4.17	328.2	-7.0	4.03	401.0	-37.2
5.76	47.0	3.1	5.78	116.2	4.0	5.76	176.4	-6.8	6.00	164.0	-35.6
7.76	27.3	2.4	7.76	56.4	3.0	7.80	86.5	-6.3	7.71	76.8	-32.6
13.63	11.4	1.4	13.57	24.2	1.7	13.63	29.4	-4.7	13.63	16.6	-22.8
22.92	5.8	1.3	21.70	12.4	1.1	22.47	13.8	-3.0	21.42	5.7	-14.4
49.11	1.4	0.9	49.15	3.1	0.6	49.21	2.8	-1.1	48.90	1.4	-5.5
113.5	0.4	0.0	105.8	1.0	0.0	111.2	1.0	-0.1	105.0	-1.0	-1.8
210.2	0.0	0.0	212.7	0.1	0.0	214.1	0.0	-0.0	210.2	-0.3	-0.4

TUNGSTEN STEEL.

$$T = 3371 \text{ gr./mm.}^2, \quad t = 13.7^\circ \text{ C.}$$

$H' = 4.01$		$H' = 10.72$		$H' = 14.53$		$H' = 18.39$		$H' = 22.40$	
τ	∂I_i	τ	∂I_i	τ	∂I_i	τ	∂I_i	τ	∂I_i
18.4'	0.9	12.9'	2.2	12.9'	4.0	13.8'	8.9	17.6'	13.4
39.8	2.2	47.5	7.1	39.1	14.4	38.4	32.6	41.4	37.0
69.2	4.9	69.2	15.7	69.2	29.3	69.5	69.9	69.2	63.3
	0.1		0		0		-0.3		-0.3

$H' = 30.07$		$H' = 46.05$		$H' = 98.8$		$H' = 209.0$		$H' = 364.0$	
τ	∂I_i	τ	∂I_i	τ	∂I_i	τ	∂I_i	τ	∂I_i
12.9'	3.4	13.4'	1.3	14.5'	0.2	13.0'	0.0	21.4'	0.0
34.8	12.4	48.4	6.6	42.7	1.5	47.6	0.0	—	—
69.2	27.2	69.2	9.1	69.2	2.3	69.2	-0.1	69.2	0.0
	-0.7		-0.8		-1.0		-0.3		-0.2

The numbers in the last row give the cyclic effect of twist corresponding to the maximum twist.

The effect of the graduated application of twist does not sensibly differ from that of applying the maximum twist at once.

(d) *Magnetization under constant twist combined with tensions:* $(I, H)_{\tau, T}$.

The effect of a constant twist on magnetization is very small; in a small twist, the magnetization slightly increases, but above a moderate twist, it is decreased by twisting. With a moderate twist, curves $(\partial I, H)_{\tau, T}$ as deduced from $(I, H)_{\tau, T}$ have an opposite sign to those deduced from $(\partial I, \tau)_{H, T}$; but they have the same sign as curves $(\partial I, H)_{\tau, T}$ obtained from $(\partial I, \tau)_{H, T}$. The following tables and the dotted curves in Figs. 13, 14 and 15 will show these changes of magnetization.

SWEDISH IRON.

$$T=152 \text{ gr./mm.}^2, \quad t=15.7^\circ \text{ C.}$$

$\tau=0$		$\tau=31.9'$		$\tau=70.3'$	
H	I	H	I	H	I
0.77	16.8	0.68	14.8	0.68	12.5
1.68	47.8	1.29	33.3	1.39	32.5
2.38	95.1	2.29	79.5	2.29	66.0
3.49	256.9	3.31	211.0	2.93	129.3
4.05	406.1	4.21	416.2	3.86	257.7
4.69	571	5.06	632	4.49	410.1
5.91	776	6.51	838	5.74	683
7.58	933	8.33	975	8.68	945
11.45	1094	12.29	1110	12.47	1064
20.51	1215	20.64	1211	20.65	1173
30.81	1266	31.08	1264	31.11	1238
50.90	1320	50.83	1319	50.91	1299
110.8	1408	110.2	1409	111.1	1403
173.5	1466	172.8	1467	173.5	1462
263.5	1524	261.0	1526	263.5	1521
358.1	1568	357.5	1569	359.3	1566

$$T=3238 \text{ gr./mm.}^2, t=15.6^\circ \text{ C.}$$

$\tau=0$		$\tau=14.2'$		$\tau=29.3'$		$\tau=58.3'$		$\tau=88.3'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
0.66	15.9	0.68	16.8	0.71	17.2	0.19	3.1	0.76	16.5
1.30	38.2	1.29	41.2	1.31	41.8	1.32	37.2	1.54	43.5
2.23	98.0	1.94	79.3	2.19	100.4	2.20	94.3	2.25	79.4
3.15	257.7	2.73	192.8	2.85	192.8	2.95	168.4	2.98	145.9
3.77	450.9	3.51	424.0	3.54	418.4	3.78	351.5	3.82	300.8
4.48	719	4.19	635	4.33	708	4.60	645	4.81	609
5.69	940	5.57	929	5.75	963	6.05	925	6.57	890
6.75	1028	6.67	1023	7.19	1064	7.99	1048	8.25	1005
13.74	1196	15.27	1210	14.75	1219	15.30	1196	12.53	1114
20.98	1250	21.09	1248	21.36	1265	21.21	1242	20.74	1206
31.06	1292	30.99	1288	31.57	1305	30.79	1288	31.00	1265
50.50	1342	51.23	1341	51.65	1356	50.91	1346	50.62	1330
115.7	1436	115.7	1436	113.3	1449	112.4	1444	111.9	1433
180.5	1499	180.5	1499	177.4	1511	175.9	1506	175.1	1496
275.2	1562	274.7	1561	270.8	1573	267.3	1568	266.3	1560
376.2	1610	376.1	1610	370.4	1621	365.6	1616	365.6	1608

TUNGSTEN STEEL.

$$T=3371 \text{ gr./mm.}^2, t=13.7^\circ \text{ C.}$$

$\tau=0$		$\tau=69.2'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
2.71	16.7	2.22	13.4
4.68	31.7	4.61	29.8
7.98	60.5	10.56	87.0
12.03	109.0	14.72	153.2
16.80	222.6	16.80	209.8
19.03	364.2	18.98	359.2
22.04	630	21.97	622
27.63	844	27.45	840
34.18	958	33.87	958
50.26	1083	42.41	1038
85.9	1185	63.2	1136
132.2	1247	105.6	1223
179.8	1272	158.4	1279
210.5	1307	212.4	1318
267.7	1334	269.1	1341
344.1	1359	343.8	1366

From the results thus far described, it may be concluded that in Swedish iron and tungsten steel, the final magnetization is affected in no inconsiderable degree by the order of magnetizing and straining. This fact stands parallel to the result of our previous experiment that in these metals, the change of elastic constants by magnetization is considerably affected by the order of applying the stress and the magnetizing field.

II. NICKEL.

The effect of stress on the magnetization of nickel has been thoroughly studied by several physicists, so that there remains little to be studied about the effect. Our present experiment has, however, this characteristic that several effects of stress on magnetization were studied with the same specimen over a wide range of the magnetizing field and with special attention to the hysteresis effect.

(a) *Change of magnetization by tension under constant field:* $(\partial I, T)_H$.

The initial effect of loading on magnetization in very weak fields is an increase of magnetization by low tension, and a decrease by high tension; but the cyclic effect is always a decrease, unlike the Villari reversal in iron. Above 2 C.G.S. units, however, the initial and the cyclic effects are always a decrease of magnetization.

In low tension, ∂I_i or ∂I_c decreases almost proportionally with T ; as T is increased, the rate of decrease becomes great, and after passing through an inflexion point, it begins to decrease, as shown in Fig. 16. As the field is increased, the decrease of magnetization passes through its maximum.

Except in weak fields, the cyclic effect $(\partial I_c, T)_H$ (Fig. 16, dotted lines) fairly coincides with the initial effect. Curves $(\partial I_c, H)_T$ deduced from $(\partial I_c, T)_H$ are given in Fig. 17, in full lines. In weak fields, they fall steeply and then gradually rise; as the field is further increased, they slowly tend to approach the axis of the field.

NICKEL.

Initial $T=167 \text{ gr./mm}^2$ $t=14.3^\circ \text{ C.}$

H'	$T=855 \text{ gr./mm}^2$		$T=1711 \text{ gr.}$		$T=3421 \text{ gr.}$		$T=5089 \text{ gr.}$		$T=8513 \text{ gr.}$	
	∂I_h	∂I_c	∂I_h	∂I_c	∂I_h	∂I_c	∂I_h	∂I_c	∂I_h	∂I_c
1.11	+6.6	-13.5	+9.7	-32.2	+3.5	-81.0	-4.1	-99.4	-9.2	-108.6
2.35	-5.5	-18.4	-18.4	-42.8	-62.7	-102.6	-85.5	-128.1	-97.8	-137.9
3.89	-10.9	-20.2	-29.2	-47.7	-83.0	-107.4	-113.8	-143.4	-132.1	-163.6
10.77	-23.4	-28.0	-52.5	-58.7	-119.2	-119.3	-170.2	-181.8	-221.3	-223.2
31.06	-23.3	-24.5	-54.0	-55.1	-122.8	-121.2	-189.2	-185.5	-267.5	-261.1
62.54	-12.4	-12.7	-29.5	-29.5	-76.0	-76.2	-127.6	-129.9	-235.5	-234.6
135.2	-4.8	-4.6	-10.6	-10.7	-25.8	-26.1	-46.4	-47.5	-113.2	-114.4
205.5	-2.0	-2.0	-4.6	-4.9	-11.3	-12.1	-20.5	-21.3	-49.3	-49.9
364.7	-0.3	—	-0.6	—	-2.1	—	-4.1	—	-11.3	—

The effect of applying the maximum tension at once is nearly the same as that of the graduated applications of tension.

The change of magnetization by tension under different initial loadings, where the demagnetization was always effected with the initial load, is given in Fig. 18. and in the following table. The full lines in the figure refer to the initial effect, while the dotted one to the cyclic effect; the initial and the cyclic effect nearly coincide with each other. As the initial tension is increased, the field of the maximum decrease is displaced toward the higher field. For the same increment ∂T of T , ∂I is in a marked degree less than that in the last experiment.

NICKEL.

$$\partial T = 1022 \text{ gr./mm}^2, \quad t = 14.3^\circ \text{ C.}$$

$T=1877 \text{ gr./mm}^2.$			$T=3546 \text{ gr./mm}^2.$			$T=5256 \text{ gr./mm}^2.$		
H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e
1.08	+3.1	-4.1	1.12	0.0	-1.7	1.17	+0.2	-0.6
2.37	-1.5	-11.0	2.47	-1.6	-3.7	2.50	-0.9	-1.5
4.04	-10.4	-15.6	3.95	-4.1	-6.4	3.89	-2.0	-2.5
10.64	-23.0	-22.8	10.79	-17.0	-17.9	10.65	-6.6	-7.2
30.60	-26.2	-26.0	31.53	-25.4	-25.1	31.51	-18.8	-18.8
62.9	-18.7	-18.4	59.90	-23.0	-23.0	59.2	-24.2	-23.0
132.8	-6.7	-6.4	136.6	-9.2	-8.7	136.3	-11.7	-11.9
227.9	-2.8	-2.5	211.3	-4.1	-4.3	210.7	-5.7	-5.7
349.7	-1.1	-0.6	349.2	-1.4	-1.4	348.5	-1.5	-1.5

(b) *Magnetization under constant tensions: $(I, H)_r$.*

The magnetization increases steeply in low fields and after passing through an inflexion point, gradually approaches saturation. The effect of tension is considerably large and always to diminish magnetization; curves $(I, H)_r$ become less steep in weak fields with the increasing tension, and tend to approach each other in strong fields. If we compare ∂I obtained from $(I, H)_r$ with that from $(\partial I, T)_n$ for the same values of H and T , the former is found to be a little numerically greater than the latter. The dotted line in Fig. 17 represents the values of ∂I as deduced from $(I, H)_r$.

NICKEL.

$$t=14.6^{\circ} \text{ C.}$$

$T=167 \text{ gr. mm.}$		$T=1022 \text{ gr.}$		$T=1878 \text{ gr.}$		$T=3588 \text{ gr.}$		$T=5256 \text{ gr.}$		$T=8680 \text{ gr.}$	
H	I	H	I	H	I	H	I	H	I	H	I
0.93	9.3	0.92	10.0	0.93	9.1	0.86	5.0	1.66	7.6	2.06	5.8
1.68	82.3	2.02	73.9	1.91	38.9	1.76	11.6	3.50	16.7	4.41	12.9
3.19	147.6	3.36	131.3	3.24	91.1	3.44	26.8	6.64	34.8	7.78	23.4
4.12	170.4	4.02	154.1	4.43	115.8	4.81	42.0	10.76	60.4	13.38	41.7
6.62	216.7	6.65	191.2	6.70	151.6	7.75	73.4	15.56	93.8	26.01	81.5
10.48	266.8	9.66	226.5	10.52	194.2	12.14	115.1	—	—	—	—
16.14	316.6	15.54	279.3	15.72	237.1	17.98	159.3	26.56	144.3	—	—
26.31	373.0	26.30	313.0	26.32	301.2	27.18	214.5	39.31	202.8	39.24	119.3
38.88	413.4	39.09	392.4	39.11	354.6	39.62	270.9	62.9	291.6	59.8	176.2
62.5	466.0	62.9	444.5	63.2	420.8	63.4	352.0	106.3	392.1	105.6	296.8
133.5	490.0	133.9	491.4	134.0	482.8	138.4	451.0	186.1	460.5	185.8	420.0
205.7	506.3	206.1	508.2	206.8	502.7	206.7	479.7	211.7	470.8	227.1	449.5
269.8	511.0	269.9	515.5	270.5	511.6	270.4	491.5	287.0	487.9	284.1	473.0
366.6	514.5	367.9	520.0	368.7	517.6	367.3	499.5	358.9	495.8	354.0	488.7

(c) *Change of magnetization by twist under different tensions:* $(\partial I, \tau)_{H, T}$.

In weak fields, the magnetization is increased by twist, but in strong fields, it is slightly diminished. As shown in Figs. 19 and 20, the curves $(\partial I, \tau)_{H, T}$ bend slightly towards the axis of the twist; the curvatures become less as the tension is increased. Except in weak fields, the initial effect is inconsiderable; it also becomes less as the tension is increased.

Curves $(\partial I, H)_{\tau}$, from $(\partial I, \tau)_{H, T}$ are drawn in Figs. 21 and 22 in full lines; they have steep positive maxima from which the curves slope down gradually to the higher field, cut the axis

of H , become negative and after passing through very inconspicuous negative maxima, very slowly bend towards the axis; the maxima become flatter with the greater tension, and the positions of the maxima as well as the points of intersection with the axis move toward higher fields with the increasing tension. The course of the curves is thus quite similar to that of curves $(\partial I, H)_T$ in the case of iron. The following tables are the numerical data obtained.

NICKEL.

$$T=1197 \text{ gr./mm.}^2, \quad t=14.9^\circ \text{ C.}$$

$H'=0.68$				$H'=1.07$				$H'=2.31$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
8.4'	22.1	9.1'	34.2	16.0'	105.3	12.2'	50.9	16.5'	27.8	13.1'	57.2
21.8	72.8	23.6	91.7	26.9	158.3	28.9	109.4	34.4	95.2	30.4	121.6
36.9	130.6	41.8	136.3	40.7	196.6	41.8	137.5	46.3	152.3	43.3	150.9
54.2	188.8	55.2	155.6	54.0	221.2	58.3	161.0	63.1	216.3	58.7	174.9
69.2	221.1	69.2	171.9	69.3	239.5	69.0	172.9	69.4	232.5	69.3	187.1

$H'=3.91$				$H'=10.62$				$H'=23.22$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
10.2'	60.2	8.0'	29.3	10.8'	45.6	7.1'	13.8	8.8'	4.6	14.0'	4.6
23.7	121.0	26.3	91.8	22.6	75.4	22.7	48.0	23.6	20.0	31.7	15.6
36.0	151.9	38.2	117.6	37.2	106.0	39.5	73.2	38.3	30.3	—	—
53.5	179.8	48.7	133.8	50.7	122.5	54.0	88.1	54.9	37.8	50.7	25.0
69.0	198.2	69.2	154.8	69.3	136.7	69.0	97.8	69.3	41.1	69.3	31.1

$H' = 50.07$				$H' = 99.7$				$H' = 168.7$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_i	τ	δI_i	τ	δI_e
11.8'	+7.3	10.1'	+3.0	9.8'	+2.4	15.4'	+0	9.9'	+1.2	11.7'	+0.6
28.8	-3.4	26.8	-7.6	25.8	-6.6	32.6	-12.5	38.5	-12.2	25.7	-5.2
46.4	-7.6	45.0	-12.2	43.9	-18.7	47.7	-22.0	58.0	-21.4	42.0	-14.8
68.9	-10.8	69.3	-15.7	69.4	-30.7	69.3	-31.8	69.3	-29.4	69.3	-30.1

$H' = 241.4$				$H' = 358.0$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
13.1'	-0.3	14.2'	0.0	18.8'	0.0	14.2'	0.0
28.9	-4.9	28.9	-4.6	38.7	-4.3	22.6	-2.3
46.6	-13.3	48.0	-13.6	53.5	-10.4	52.0	-9.6
69.3	-25.6	69.3	-19.3	69.3	-14.2	69.3	-15.8

$$T = 3546 \text{ gr./mm.}^2, \quad t = 14.7^\circ \text{ C.}$$

$H' = 0.17.$				$H' = 0.96$				$H' = 2.40$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
6.1'	0.5	7.6'	10.7	7.4'	4.6	9.6'	14.0	10.0'	20.4	9.7'	31.0
21.1	2.6	24.7	35.5	17.8	11.3	27.5	41.8	23.2	46.8	28.0	89.4
38.7	8.7	34.2	47.3	32.7	20.4	48.0	66.7	36.9	70.2	43.7	129.7
58.2	21.4	52.3	63.6	51.3	32.5	—	—	55.2	104.7	—	—
68.5	31.4	68.5	76.2	68.5	44.4	68.5	85.3	68.5	133.0	68.5	174.6

$H'=4.06$				$H'=10.61$				$H'=24.37$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
8.2'	35.9	7.3'	24.0	7.4'	26.0	9.2'	24.0	6.6'	8.9	8.8'	26.3
22.4	84.9	23.4	78.5	20.8	70.7	24.6	66.4	20.4	36.3	25.0	52.3
37.3	131.4	38.4	121.3	38.5	117.5	42.3	107.3	37.4	64.0	41.5	75.5
53.6	169.1	49.8	147.3	51.0	142.3	—	—	48.8	79.1	55.7	91.2
68.5	196.8	68.5	179.6	68.5	168.2	68.5	146.9	68.5	97.4	68.5	102.0

$H'=49.16$				$H'=94.4$				$H'=168.3$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
7.6'	5.2	10.6'	2.7	8.9'	+3.0	11.2'	-1.1	12.8'	+1.1	10.9'	0.0
24.3	14.3	24.7	9.2	24.0	-6.4	28.4	-13.3	29.3	-8.4	32.8	-12.2
36.4	20.5	45.6	16.6	38.7	-15.8	45.1	-18.8	49.0	-20.7	51.6	-23.4
50.3	26.0	—	—	51.0	-19.1	—	—	—	—	—	—
68.5	31.8	68.5	23.9	68.5	-22.9	68.5	-24.3	68.5	-31.0	68.5	-31.3

$H'=253.9$				$H'=358.7$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
10.1'	-0.3	17.0'	-1.8	12.2'	0.0	12.5'	0.0
27.3	-6.2	35.1	-10.4	28.7	-3.0	29.5	-4.4
47.0	-17.0	53.7	-19.6	48.0	-9.9	47.1	-11.1
68.5	-28.0	68.5	-27.2	68.3	-18.1	68.5	-19.2

$$T=6286 \text{ gr./mm.}^2, \quad t=147^\circ \text{ C.}$$

$H'=2.38$				$H'=3.99$				$H'=10.64$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
9.3'	1.8	3.8'	15.4	10.1'	13.9	11.6'	24.5	7.1'	16.9	9.9'	19.4
24.0	5.5	29.8	43.0	24.8	36.3	26.1	55.0	20.4	42.8	26.8	53.5
38.1	11.3	45.4	66.2	39.8	61.9	41.7	88.8	33.8	73.8	42.3	91.8
51.3	20.5	—	—	58.2	95.3	50.6	107.2	51.3	116.5	57.0	121.0
68.8	37.3	68.8	100.8	68.8	116.4	68.8	142.4	68.8	152.5	68.8	141.5

$H'=24.08$				$H'=49.02$				$H'=94.9$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
6.6'	7.9	9.3'	10.4	10.9'	4.7	11.2'	3.0	8.6'	3.5	14.4'	1.5
23.8	36.7	26.9	40.8	23.5	20.7	27.3	21.4	22.9	4.7	31.8	2.6
36.1	63.7	44.1	75.9	40.3	42.0	45.4	44.3	38.7	6.3	—	—
55.4	100.8	56.3	97.6	57.0	61.7	—	—	53.7	8.7	50.3	5.3
68.8	120.4	68.8	115.5	68.8	72.9	68.8	67.7	68.8	10.4	68.8	7.9

$H'=168.7$				$H'=254.0$				$H'=351.2$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
9.9'	+2.1	10.5'	+0.9	7.8'	+1.1	9.9'	+0.9	11.7'	+0.5	17.0'	-0.5
23.2	-5.9	29.2	-9.4	28.9	-6.4	28.5	-5.6	29.8	-4.0	34.6	-6.4
43.5	-15.4	50.3	-19.3	45.4	-14.9	—	—	49.6	-12.1	48.7	-13.1
68.8	-25.8	68.8	-26.0	68.8	-26.4	68.8	-28.1	68.8	-20.9	68.8	-22.2

The effect of the graduated application of twist does not sensibly differ from that obtained by applying the maximum twist at once.

(d) *Magnetization under constant twist combined with tensions*: $(I, H)_{\tau, T}$.

The effect of a constant twist on magnetization is to increase the magnetization in weak fields and to diminish it in strong fields. As for curves $(\partial I, H)_{\tau, T}$ (dotted lines in Figs. 21 and 22) deduced from $(I, H)_{\tau, T}$, the general course is quite similar to that of the curves obtained from $(\partial I, \tau)_{H, T}$; but quantitatively there is some difference between these two. The difference, however, becomes less with increased tension.

NICKEL.

$$T=1197 \text{ gr./mm.}^2, \quad t=13.7^\circ \text{ C.}$$

$\tau=0$		$\tau=11.4'$		$\tau=34.5$		$\tau=67.0$	
H	I	H	I	H	I	H	I
0.87	6.5	0.81	6.1	0.79	4.2	0.79	5.0
1.88	57.0	1.78	47.4	2.00	80.5	1.34	68.8
4.71	151.7	3.07	102.0	3.40	135.3	1.98	133.2
7.68	196.0	4.99	147.1	5.32	211.7	4.04	262.6
10.05	222.0	8.11	195.3	8.36	273.7	8.44	310.5
14.49	262.1	12.48	248.5	11.95	302.6	13.61	328.8
35.74	371.0	34.12	360.9	33.79	368.4	33.80	366.2
60.4	429.9	52.7	406.1	52.85	398.7	52.68	387.7
125.1	484.0	104.1	463.5	105.3	448.7	104.6	425.7
182.2	502.7	169.1	491.0	171.0	478.7	169.3	454.2
218.4	509.2	220.4	501.6	222.5	491.1	220.4	468.0
304.4	518.6	289.9	508.1	282.8	500.4	279.7	479.1
369.1	522.0	356.9	512.7	363.2	507.9	357.3	489.1

$$T=3546 \text{ gr./mm.}^2, \quad t=13.7^\circ \text{ C.}$$

$\tau=0$		$\tau=11.8'$		$\tau=34.6'$		$\tau=66.9'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
0.80	4.8	0.79	4.1	0.80	3.5	0.79	2.7
2.01	13.5	1.98	12.3	1.77	9.4	1.75	14.8
3.80	29.9	3.11	22.1	2.98	24.6	2.84	106.4
6.55	59.5	4.65	37.3	4.53	57.6	4.06	191.5
9.73	91.5	6.86	60.3	6.98	123.0	6.52	248.5
15.03	136.4	11.67	107.3	12.08	195.4	11.22	277.4
23.30	191.4	17.51	156.0	22.53	250.5	22.08	310.6
33.86	245.0	33.48	249.7	33.68	287.2	33.15	333.9
54.1	321.3	57.28	322.6	51.85	332.2	52.87	367.3
113.6	430.2	101.8	414.9	113.3	418.8	112.3	425.6
170.7	462.6	162.3	458.9	171.0	454.3	169.3	456.5
253.7	483.7	275.8	487.4	252.8	479.5	251.6	482.2
354.0	499.1	356.9	494.7	353.7	493.1	350.5	500.1

$$T=6286 \text{ gr./mm.}^2, \quad t=13.7^\circ \text{ C.}$$

$\tau=0$		$\tau=11.8'$		$\tau=34.6'$		$\tau=69.0'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
1.46	5.6	1.17	3.8	1.39	4.0	0.88	2.6
3.03	11.7	2.53	8.4	3.12	11.4	3.14	25.5
5.04	21.9	4.26	16.0	4.89	21.7	5.40	158.4
8.92	43.1	9.89	43.9	7.80	58.8	8.16	211.9
14.29	72.3	15.38	74.3	11.58	119.7	13.27	232.0
23.67	114.8	23.86	119.5	23.35	175.9	23.77	260.3
34.77	156.8	34.93	162.2	34.98	211.0	35.36	285.7
57.33	229.7	56.8	234.7	56.2	268.9	56.58	325.7
98.6	341.0	88.8	321.6	88.1	338.5	88.1	372.5
161.7	429.0	134.3	396.3	147.6	412.3	147.3	427.6
195.5	451.2	190.4	441.9	196.3	444.6	196.2	445.2
272.7	478.7	270.2	471.5	267.5	471.4	267.5	481.3
381.7	465.7	380.5	489.8	375.4	491.3	373.0	503.8

It is to be noticed that in nickel, the initial and the cyclic effects of tension or twist on magnetization nearly coincide with each other except in weak fields, and that the change of magnetization does not much depend on the order of magnetizing and straining. Thus, in nickel, the hysteresis effect is comparatively small except in weak fields; and therefore the agreement between the theory regarding magnetostriction and the experiment might well have been expected. Thus, in our previous experiment, we found that the changes of the modulus of elasticity by magnetization for different orders of magnetizing and straining fairly coincided with each other, while in the case of rigidity, the difference was somewhat greater. In the present experiment also, the tension effect shows a better agreement for different orders of magnetizing and straining than for the torsion effect.

III. NICKEL STEELS containing 28.74, 50.72 and 70.32 per cent of Nickel.

As for nickel steels, experiments on the effect of stress on magnetization have been very few. So far as we know, the effect of tension only was studied by H. Tomlinson¹⁾ with nickel steels of 22, 25 and 30 per cent of nickel, and by Professor H. Nagaoka and one of us²⁾ with nickel steels of 35 and 45 per cent of nickel. Hence somewhat detailed descriptions of the phenomena will not be unnecessary.

(a) *Change of magnetization by tension under constant field: $(\partial I, T)_H$*

The magnetization increases at first rather rapidly, but after-

1) Tomlinson, Proc. Roy. Soc. **56**, p. 103, 1894; Beibl. **18**, 952.

2) Nagaoka and Honda, Jour. Coll. Sci., **16**, Art. 8, 1902.

ward slowly with the tension. The increase in low fields is tolerably large, but in strong fields, it is very small. The initial effect is significant only for weak fields, where the cyclic is remarkably less than the initial. The following tables and Figs. 23, 24 and 25 show these changes of magnetization.

Curves $(\partial I_i, H)_T$ from $(\partial I_i, T)_H$ rise rapidly with the field, attain sharp maxima at low fields, fall at first rapidly and then gradually to asymptotic values, as shown in Figs. 26, 27 and 28 in full lines. The maximum of ∂I increases with tension. For the same tension, the maximum rapidly increases with the percentage content of nickel.

28.74% NICKEL STEEL.

Initial $T=134 \text{ gr./mm.}^2$ $t=14.0^\circ \text{ C.}$

H'	$T=1370 \text{ gr./mm.}$		$T=2706 \text{ gr.}$		$T=4077 \text{ gr.}$		$T=6818 \text{ gr.}$	
	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e
0.11	1.1	8.8	—	—	22.2	30.3	36.0	35.3
0.25	20.1	26.4	62.4	57.5	97.5	77.6	130.3	94.1
0.49	46.7	31.8	97.6	64.7	129.2	86.1	155.5	104.0
1.11	43.4	31.7	78.0	59.9	97.6	76.4	113.0	90.0
2.30	31.6	26.8	52.2	45.7	63.3	56.1	72.2	64.5
4.65	18.8	17.2	28.9	27.0	34.0	32.0	38.6	36.3
10.68	5.9	5.3	—	—	11.0	10.0	13.8	12.8
24.32	2.3	2.0	—	—	5.9	5.3	8.8	8.0
55.48	1.5	1.6	—	—	4.9	4.9	7.8	8.0
172.9	1.5	1.3	—	—	4.4	4.1	7.4	7.0
374.3	1.4	1.3	—	—	4.0	3.9	6.6	6.6

50.72% NICKEL STEEL.Initial $T=160 \text{ gr./mm.}^2$, $t=13.7^\circ \text{ C.}$

H'	$T=1645 \text{ gr./mm.}^2$		$T=3249 \text{ gr.}$		$T=4894 \text{ gr.}$		$T=6540 \text{ gr.}$		$T=8185 \text{ gr.}$	
	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e
0.29	103.3	91.0	222.6	138.8	277.8	153.2	300.3	155.1	311.0	153.7
0.70	266.7	140.5	437.9	212.1	503.9	233.3	528.3	235.1	539.7	232.0
1.27	319.8	157.3	476.3	233.4	534.8	254.9	552.3	255.9	557.1	250.0
1.95	253.1	148.7	359.2	215.4	392.0	230.3	397.7	227.5	390.2	219.4
2.76	196.6	136.8	276.3	193.9	298.7	207.3	299.8	204.1	294.0	195.2
5.52	134.5	108.8	186.4	151.3	202.5	162.5	204.0	161.1	199.1	154.4
10.71	84.4	75.4	113.8	102.0	122.5	109.4	123.4	109.4	120.5	106.0
23.77	34.2	32.8	46.1	43.5	49.4	46.6	—	46.6	47.9	45.0
51.44	7.9	7.7	10.7	10.5	11.7	11.0	—	—	10.2	9.2
151.4	0.7	0.4	0.9	0.4	0.9	0.4	—	—	0.2	0.0
360.0	0.0	0.0	0.0	0.0	0.0	0.0	—	—	0.0	0.0

70.32% NICKEL STEEL.Initial $T=156 \text{ gr./mm.}^2$, $t=14.5^\circ \text{ C.}$

H'	$T=1604 \text{ gr./mm.}^2$		$T=3170 \text{ gr.}$		$T=4774 \text{ gr.}$		$T=6379 \text{ gr.}$		$T=7984 \text{ gr.}$	
	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e	∂I_i	∂I_e
0.13	25.7	32.5	90.0	58.1	111.3	65.1	107.0	66.3	94.5	67.2
0.29	44.4	45.5	94.5	—	109.6	85.2	119.2	—	132.4	91.3
0.70	182.4	143.5	473.3	225.0	582.4	296.3	635.1	—	665.1	339.1
1.08	342.3	152.0	586.5	260.4	666.2	316.6	703.5	—	728.0	364.7
1.49	321.4	149.2	482.5	246.0	546.0	298.3	578.8	—	600.2	344.6
2.66	198.1	131.6	301.5	208.6	352.2	249.8	379.2	—	381.6	287.8
5.05	113.3	93.2	168.5	142.7	199.8	171.1	—	—	228.2	198.4
10.69	46.9	42.5	70.7	65.7	85.7	80.2	—	—	101.7	95.7
24.52	10.7	10.3	17.5	17.5	23.8	22.3	—	—	28.4	28.2
49.70	1.8	2.0	—	—	4.7	4.5	—	—	6.4	6.2
129.3	0.4	—	—	—	0.7	—	—	—	0.8	—
227.0	0.0	—	—	—	0.0	—	—	—	0.1	—
393.2	0.0	—	—	—	0.0	—	—	—	0.0	—

The effect of applying the maximum tension at once does not materially differ from that obtained by graduated application of it.

The change of magnetization by tension under different initial loadings nearly coincides with the above result in the case of

28.74% Ni; but in 50.72% Ni. and 70.32% Ni., the change is generally greater in the present case than in the former, as may be seen from the following table.

28.74% NI. $t=14.2^{\circ} C.$ **70.32% NICKEL STEEL.** $t=14.1^{\circ} C.$

$T=1504 \text{ gr.}$ $\partial T=1373 \text{ gr.}$			$T=959 \text{ gr.}$ $\partial T=803 \text{ gr.}$			$T=1760 \text{ gr.}$ $\partial T=803 \text{ gr.}$			$T=3326 \text{ gr.}$ $\partial T=1605 \text{ gr.}$		
H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e
0.18	8.8	2.5	0.13	-2.4	-4.7	0.13	-3.3	-5.8	0.13	-11.6	-12.0
0.29	39.6	15.6	0.30	+4.2	-1.0	0.29	+0.8	-5.7	0.29	+18.4	-11.0
0.68	49.8	25.8	0.68	65.3	+15.6	0.68	74.9	+5.9	0.72	49.7	+1.4
1.12	35.6	25.9	1.10	189.5	45.5	1.08	149.1	32.6	1.20	128.2	36.9
1.92	24.6	20.7	1.49	163.5	56.8	1.48	111.2	44.4	1.59	81.2	40.1
3.55	13.8	13.0	2.68	92.8	55.4	2.69	62.1	39.7	2.67	54.2	35.9
7.09	5.7	5.6	5.09	48.6	39.6	5.01	34.1	28.1	5.08	30.3	25.3
14.94	2.2	2.2	10.67	19.5	17.9	10.66	13.8	13.2	10.69	14.7	13.6
38.37	1.6	1.6	25.81	4.2	4.2	25.65	3.5	3.4	25.92	4.2	4.1
115.6	1.5	1.3	49.83	0.9	0.9	52.5	0.6	0.6	49.8	1.2	1.0
212.0	1.3	1.3	106.5	0.3	0.1	106.9	0.1	0.1	107.6	0.0	0.1
313.1	1.2	1.2	205.5	0.0	0.0	208.5	0.0	0.0	208.8	0.0	0.0

50.72% NICKEL STEEL. $t=14.2^{\circ} C.$

$T=983 \text{ gr.}$ $\partial T=823 \text{ gr.}$			$T=1805 \text{ gr.}$ $\partial T=823 \text{ gr.}$			$T=3410 \text{ gr.}$ $\partial T=823 \text{ gr.}$			$T=5054 \text{ gr.}$ $\partial T=823 \text{ gr.}$		
H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e	H'	∂I_i	∂I_e
0.26	32.9	14.8	0.29	14.8	-4.0	0.28	3.7	-4.7	0.30	-0.4	-2.1
0.88	159.3	36.1	0.84	95.3	+13.4	0.88	41.6	+1.2	0.84	+17.7	-1.5
1.60	139.6	56.1	1.48	100.5	29.3	1.48	47.3	7.4	1.48	26.7	+0.4
2.07	109.7	55.0	2.05	77.4	33.6	2.07	41.4	10.3	2.17	17.5	1.7
2.93	83.7	55.1	2.87	58.5	33.8	2.86	25.6	10.4	3.86	7.1	1.6
4.29	64.5	48.5	4.07	43.8	30.3	3.90	18.3	9.2	6.66	3.3	1.5
5.65	54.6	43.0	5.55	34.5	26.4	5.57	12.7	7.7	—	—	—
10.67	32.7	28.6	10.73	19.6	16.1	10.75	6.1	4.9	18.66	0.9	0.4
19.24	17.7	15.4	23.97	8.7	7.2	23.88	2.2	2.2	42.53	0.0	0.0
46.49	4.4	3.5	50.44	1.9	1.9	47.83	0.6	1.2	—	—	—
172.4	0.0	0.1	166.1	0.0	0.0	167.2	0.0	0.0	168.0	0.0	0.0
355.0	0.0	0.0	321.0	0.0	0.0	355.0	0.0	0.0	354.0	0.0	0.0

(b) *Magnetization under constant tensions: $(I, H)_T$.*

Among other ferromagnetic metals and alloys, nickel steels are characterized by the extraordinary steepness of the curve of magnetization; in a field of 5 C.G.S. units, the magnetization attains a value which is only a little short of its saturation value. The steepness increases with tension, first rapidly and then gradually to an asymptotic value. The enormous values of susceptibility α are given in the following table and plotted in Fig. 29. It will be noticed that the maximum value increases with the percentage of nickel. In 70.32% Ni., the susceptibility even attains a maximum value of 1015 for $T=4930$ gr./mm², which is several times greater than the maximum susceptibility of a well annealed Swedish iron. In very weak fields, the magnetization is considerably increased by tension, but in higher fields comparatively little.

<i>H</i>	28.74% Ni.		50.72% Ni.		70.32% Ni.	
	α		α		α	
	$T=134$ gr.	$T=6952$ gr.	$T=160$ gr.	$T=8344$ gr.	$T=156$ gr.	$T=4930$ gr.
0.20	75	90	55	10	10	33
0.30	110	390	110	25	17	95
0.40	125	530	153	75	28	200
0.60	145	445	243	380	64	470
0.80	150	367	337	710	120	1015
1.00	140	297	410	800	230	860
1.30	124	230	467	685	296	677
1.60	113	190	442	593	288	570
2.00	99	157	397	503	270	470
3.00	73	107	299	370	220	322
5.00	50	64	202	232	160	196
7.00	36	46	150	170	123	140

Curves $(\delta I, H)_T$ (Figs. 26, 27 and 28, dotted lines) deduced from $(I, H)_T$ take a course quite similar to those deduced from $(\delta I, T)_H$. In 28.74% Ni., the maximum δI is generally greater, and the asymptotic value decidedly greater than in $(\delta I, T)_H$ for the same tension and field. On the contrary, δI of 50.72% Ni. is always less than the corresponding value in the last experiment. In 70.32% Ni., there is a fair coincidence between the two values of δI .

28.74% NICKEL STEEL.

$$t=14.0^\circ \text{ C.}$$

$T=134 \text{ gr./mm}^2.$		$T=1504 \text{ gr.}$		$T=4211 \text{ gr.}$		$T=6952 \text{ gr.}$	
H	I	H	I	H	I	H	I
0.23	20.8	0.22	26.8	0.13	7.9	0.09	3.8
0.72	108.6	0.73	178.4	0.24	63.0	0.24	41.6
0.77	114.0	1.02	204.8	0.33	167.9	0.30	118.9
1.33	162.8	1.41	225.2	0.52	243.3	0.53	260.6
2.00	192.1	2.53	257.4	0.82	272.1	0.77	280.9
3.26	225.5	3.63	274.1	1.21	286.5	1.24	295.5
4.76	249.1	7.31	299.7	4.08	320.3	3.36	317.6
12.11	287.1	12.83	312.0	11.57	339.6	11.28	338.6
19.27	296.0	19.12	318.0	18.96	346.1	18.96	345.6
24.06	299.7	24.44	321.4	24.31	349.1	24.32	349.0
50.1	308.8	50.1	330.2	49.75	357.7	49.9	357.8
123.8	320.3	123.5	341.0	122.4	368.5	122.4	368.7
230.5	329.0	229.0	349.7	227.9	377.2	227.5	377.2
374.8	337.2	372.6	357.8	370.2	385.2	370.9	385.1

50.72% NICKEL STEEL.

 $t=13.1^{\circ} C.$

$T=983 \text{ gr./mm}^2.$		$T=3450 \text{ gr.}$		$T=5054 \text{ gr.}$		$T=6699 \text{ gr.}$		$T=8344 \text{ gr.}$	
H	I	H	I	H	I	H	I	H	I
0.30	34.0	0.32	28.6	0.33	24.7	0.31	23.3	0.38	15.4
0.51	96.5	0.48	130.0	0.50	160.4	0.49	113.7	0.49	80.6
0.75	262.6	0.59	314.7	0.62	361.1	0.66	458.6	0.63	285.9
1.48	739	0.85	597	0.89	681	1.08	839	0.80	561.8
1.73	810	1.41	899	1.38	928	1.64	996	0.90	717
2.62	949	2.15	1043	2.12	1062	2.83	1118	1.58	964
4.01	1028	3.83	1143	4.42	1177	4.58	1180	3.05	1106
4.92	1064	5.49	1181	6.87	1215	7.57	1224	7.27	1201
17.01	1210	10.88	1229	11.96	1244	13.79	1253	12.94	1232
23.73	1235	22.62	1260	22.78	1267	23.17	1271	22.95	1253
43.47	1267	43.06	1279	42.80	1283	43.22	1287	42.81	1269
110.9	1290	107.0	1295	105.6	1298	105.3	1302	105.3	1284
234.8	1298	228.0	1302	225.5	1305	224.6	1310	226.1	1292
384.1	1302	371.5	1306	367.9	1309	367.3	1314	366.7	1296

70.32% NICKEL STEEL.

 $t=13.5^{\circ} C.$

$T=156 \text{ gr./mm}^2.$		$T=959 \text{ gr.}$		$T=1761 \text{ gr.}$		$T=3366 \text{ gr.}$		$T=4930 \text{ gr.}$	
H	I	H	I	H	I	H	I	H	I
0.25	18.5	0.23	21.9	0.31	26.9	0.26	18.5	0.24	9.5
0.79	94.5	0.75	128.8	0.70	162.2	0.46	132.9	0.43	180.6
0.86	127.9	0.90	327.5	0.85	557.8	0.57	206.5	0.60	289.0
1.13	325.4	1.53	609	1.74	758	0.74	478.8	0.64	347.7
1.52	430.4	1.78	654	2.80	841	0.85	738	0.71	532.0
1.80	503.6	2.77	763	3.83	884	2.20	903	0.76	734.
4.66	769.	5.77	892	6.32	937	3.56	946	1.45	906
8.04	871	10.00	955	11.53	985	6.72	981	3.38	970
11.93	927	19.28	1008	19.67	1016	19.26	1026	6.75	996
26.54	998	24.76	1022	25.14	1028	24.63	1034	24.02	1032
50.9	1022	51.2	1045	52.0	1047	51.1	1049	50.9	1043
104.4	1030	103.2	1052	104.3	1055	102.5	1054	99.0	1048
204.4	1033	204.1	1054	202.3	1057	200.6	1056	201.0	1049
370.0	1034	368.5	1055	365.0	1057	362.6	1057	365.1	1051

(c) *Change of magnetization by twist under different tensions:* $(\partial I, \tau)_{H, T}$.

In very low fields, the magnetization considerably increases with twist; in higher fields, it first increases, but afterward begins to decrease with the twist, and in still higher fields, the magnetization decreases nearly uniformly with the twist, as shown in Figs. 30, 32, 34, 36, 38 and 39. The change of magnetization rapidly increases with the percentage content of nickel.

As for the cyclic effect (Figs. 31, 33, 35, 37, 38 and 40), it coincides fairly with the initial, except in weak fields. In 28.74% Ni. and 70.32% Ni., the increase of magnetization is only observable in very weak fields, and the magnetization generally decreases with twist. In 50.72% Ni, the magnetization first increases with the twist, attains a maximum, and then decreases. As the tension is increased, the change becomes gradually less.

Curves $(\partial I, H)_{\tau, T}$ (Figs. 41, 42, 43, 44, 45, 46 and 47 in full lines) obtained from $(\partial I, \tau)_{H, T}$ rise and fall steeply in a very low field, cut the axis of H , become negative, and after passing through rather conspicuous negative maxima, slope away gradually toward the axis, with the increasing field. ∂I is numerically greater for a greater twist. In 50.72% Ni., however, ∂I for a small twist is always positive, tending to zero, as the field increases.

Curves $(\partial I, H)_{\tau, T}$ for cyclic effect shown in the same figures are similar to the above curves, and become coincident with them above a moderate field. The increase of magnetization with small twists becomes less as the tension increases; and for 28.74% Ni. and 70.32% Ni., it almost vanishes at a high tension.

28.74% NICKEL STEEL.

$$T=959 \text{ gr./mm.}^2, \quad t=14.2^\circ \text{ C.}$$

$H'=0.10$				$H'=0.21$				$H'=0.48$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.5'	5.4	—	—	13.2'	8.6	13.4'	2.1	14.8'	15.8	17.6'	+1.5
34.5	12.7	36.9'	0.9	38.8	23.3	35.6	2.7	40.2	28.6	41.1	-0.1
68.3	18.9	68.3	1.6	68.2	36.2	68.3	2.0	68.3	31.0	68.3	-2.7

$H'=1.07$				$H'=1.86$				$H'=3.70$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
13.7'	+4.8	15.8'	-2.1	17.8'	-2.4	14.5'	-3.9	15.9'	-5.3	15.4'	-5.4
37.4	+2.3	35.4	-7.2	43.6	-12.2	38.2	-13.9	56.4	-15.9	41.8	-19.8
68.3	-4.2	68.3	-22.0	68.3	-20.9	68.3	-24.6	68.3	-30.7	68.2	-31.7

$H'=6.70$				$H'=14.51$				$H'=30.56$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.8'	-8.9	14.7'	-4.7	13.5'	-1.3	12.4'	-1.1	15.9'	-0.4	18.3'	-0.9
43.4	-18.5	36.7	-15.7	38.7	-7.2	38.7	-7.6	39.4	-2.3	42.1	-3.1
68.2	-29.9	68.3	-30.5	68.3	-15.8	68.2	-16.6	68.2	-5.9	68.2	-6.1

$H'=61.0$				$H'=168.5$				$H'=355.7$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
32.9'	-0.6	30.4'	-0.4	37.9'	0.0	—	—	36.1'	-0.1	—	—
68.2	-2.1	68.2	-2.0	68.2	-0.1	68.2'	-0.1	68.2	-0.1	—	—

$$T=1778 \text{ gr./mm.}^2, \quad t=14.2^\circ \text{ C.}$$

$H'=0.13$				$H'=0.25$				$H'=0.50$			
τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c
13.0'	6.1	16.6'	-1.0	12.4'	12.6	16.0'	-0.4	12.0'	14.8	13.8'	-1.0
36.2	18.3	41.5	-1.6	43.5	37.4	41.7	-3.2	40.0	24.2	41.8	-7.6
68.2	26.5	68.2	-1.6	68.2	46.2	68.8	-5.5	68.8	22.6	68.8	-13.7

$H'=1.08$				$H'=1.91$				$H'=3.58$			
τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c
16.5'	+1.6	13.5'	-3.7	13.2'	-2.3	16.8'	-6.1	14.0'	-3.7	15.8'	-5.3
38.6	-5.6	39.4	-15.6	40.9	-15.6	37.4	-17.4	40.1	-17.5	41.1	-19.1
68.8	-16.3	68.8	-26.5	68.8	-28.1	68.8	-31.7	68.8	-31.9	68.8	-32.9

$H'=6.81$				$H'=14.61$				$H'=33.61$			
τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c
14.7'	-3.4	14.0'	-3.3	14.1'	-1.2	15.6'	-1.5	—	—	—	—
39.9	-14.7	39.8	-14.9	42.3	-7.3	39.7	-6.6	36.6'	-1.2	32.5'	-1.3
68.8	-27.8	68.8	-28.1	68.8	-14.7	68.8	-14.8	68.8	-4.0	68.8	-4.3

$H'=68.0$				$H'=172.0$			
τ	∂I_i	τ	∂I_c	τ	∂I_i	τ	∂I_c
35.0'	-0.3	26.9'	-0.3	—	—	—	—
68.8	-1.3	68.8	-1.3	68.8'	0.0	—	—

$$T=4211 \text{ gr./mm.}^2, \quad t=14.2^\circ \text{ C.}$$

$H'=0.13$				$H'=0.24$				$H'=0.48$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.4'	8.6	17.1	0.0	14.3'	16.3	15.4'	-1.3	14.9'	19.7	16.1'	-4.4
41.2	29.7	39.6	0.0	40.6	46.3	40.1	-6.9	39.2	27.4	39.6	-16.7
68.8	41.7	69.0	1.0	69.0	61.0	69.0	-12.2	69.0	22.6	69.0	-29.9

$H'=1.09$				$H'=1.90$				$H'=3.60$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
16.1'	-1.6	15.6'	-5.1	13.6'	-2.6	18.9'	-6.1	14.9'	-2.8	16.5'	-4.0
41.6	-14.8	38.6	-18.7	43.4	-15.2	42.3	-19.2	42.6	-15.3	40.5	-15.2
69.0	-28.9	69.0	-34.6	69.0	-31.2	69.0	-33.2	69.0	-27.7	69.0	-29.1

$H'=6.78$				$H'=14.76$				$H'=35.58$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.2'	-2.3	17.1'	-2.7	14.9'	-0.9	16.6'	-1.2	18.6'	-0.4	20.6'	-0.5
41.7	-11.0	40.5	-10.4	38.8	-4.5	38.8	-4.8	46.0	-1.7	43.5	-1.7
69.0	-21.8	69.0	-21.5	69.0	-11.0	69.0	-11.2	69.0	-3.3	69.0	-3.5

$H'=66.7$				$H'=175.9$				$H'=354.6$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
19.7'	-0.1	26.3'	0.0	15.9'	0.0	—	—	—	—	—	—
69.0	-1.2	69.0	-1.1	69.0	0.0	69.0'	-0.2	69.0'	0.0	69.0'	-0.2

50.72% NICKEL STEEL.

$$t = 14.3^{\circ} \text{ C.}$$

$H' = 0.28$				$H' = 0.68$				$H' = 1.38$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.1'	22.4	17.2'	8.7	12.8'	51.3	10.4'	6.2	13.0'	55.9	10.5'	9.3
29.4	57.7	35.2	19.8	27.6	118.8	30.7	16.9	26.9	117.9	32.5	23.1
43.2	100.2	53.3	30.3	54.3	254.1	48.9	21.8	47.4	199.0	54.6	11.3
67.9	171.7	68.2	34.7	68.0	305.6	68.1	16.2	67.9	225.0	67.9	-3.9

$H' = 1.83$				$H' = 3.43$				$H' = 5.46$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
10.7'	42.2	14.2'	15.2	14.8'	35.6	12.4'	16.6	10.9'	19.8	13.9'	17.4
26.9	106.8	34.6	27.3	29.3	56.7	27.8	28.7	26.1	38.1	31.4	26.6
46.0	149.6	51.4	18.0	45.7	60.8	49.0	19.7	51.0	33.6	49.6	15.5
67.7	150.9	67.9	-4.7	67.9	37.8	67.7	-9.0	67.7	12.5	67.7	-9.6

$H' = 12.62$				$H' = 24.57$				$H' = 49.61$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
12.0'	13.2	9.8'	8.6	12.0'	8.1	16.6	10.1	15.2'	4.5	17.7'	4.8
38.2	22.8	31.0	18.9	40.6	12.0	39.7	12.0	40.4	5.7	39.0	5.4
52.4	13.8	54.3	6.8	—	—	—	—	—	—	—	—
67.7	-2.7	67.7	-8.3	67.7	-3.6	67.7	-4.7	67.7	-1.8	67.7	-2.7

$H' = 108.8$				$H' = 211.8$				$H' = 377.4$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
16.7'	1.7	15.7'	1.5	15.7'	0.7	15.8'	0.6	10.9'	-0.2	—	—
43.1	1.7	43.6	1.5	45.0	0.7	43.6	0.6	—	—	—	—
67.7	-1.1	67.7	-1.5	67.7	-0.2	67.7	-0.3	67.7	-0.2	—	—

$$T=3409 \text{ gr./mm.}^2, \quad t=14.3^\circ \text{ C.}$$

$H'=0.28$				$H'=0.69$				$H'=1.28$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
12.4'	13.5	11.2'	2.1	12.6'	38.2	11.1'	4.5	12.1'	35.0	13.5'	9.3
29.7	42.4	30.1	4.1	28.9	88.3	27.7	9.0	27.7	83.6	30.7	15.5
52.0	91.7	46.2	5.6	46.0	131.6	46.5	9.0	43.3	122.8	49.6	11.4
67.9	121.5	67.9	5.6	67.9	182.9	67.9	3.0	67.9	153.2	67.9	-2.6

$H'=1.82$				$H'=4.16$				$H'=10.54$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
11.9'	35.6	10.7'	9.5	11.0'	18.0	11.2'	11.7	11.2'	10.1	11.8'	9.0
31.2	81.3	26.9	18.6	27.8	35.0	28.0	22.0	29.1	18.1	38.7	16.3
53.0	108.0	46.5	15.2	46.5	36.1	47.9	15.5	47.6	13.8	50.5	8.9
67.9	108.2	67.9	-4.7	67.9	18.0	67.9	-5.6	67.7	-2.7	67.7	-6.2

$H'=24.62$				$H'=49.35$				$H'=109.0$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
11.3'	5.7	10.9'	4.8	11.8'	3.0	10.7'	2.7	15.2'	1.5	12.0'	1.4
27.7	9.8	28.6	8.9	28.0	4.5	25.4	4.8	41.9	1.5	44.2	1.4
47.3	6.9	48.6	5.7	51.0	2.4	46.7	3.5	—	—	—	—
67.7	-3.3	67.7	-4.2	67.7	-2.4	67.9	-2.3	67.7	-0.6	67.7	-0.5

$H'=212.8$				$H'=376.8$			
τ	δI_i	τ	δI_e	τ	δI_i	τ	δI_e
17.7'	0.3	13.2'	0.8	23.0	0.0	21.9	0.0
35.1	0.3	37.8	0.8	—	—	—	—
67.7	-0.8	67.7	0.3	67.7	-0.3	67.7	-0.2

70.32% NICKEL.

$$T=1123 \text{ gr./mm.}^2, \quad t=12.7^\circ \text{ C.}$$

$H'=0.29$				$H'=0.69$				$H'=0.89$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
22.6'	77.0	25.3'	4.4	16.2'	89.0	23.2'	14.1	16.6'	128.2	17.9'	7.9
—	—	—	—	35.5	212.7	—	—	37.3	324.0	42.0	32.7
48.5	118.1	48.9	1.9	54.5	295.0	49.4	34.0	55.7	394.6	—	—
69.3	121.9	69.3	-1.0	69.3	341.0	69.3	42.9	69.3	420.8	69.0	44.5

$H'=1.70$				$H'=3.08$				$H'=4.64$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
14.3'	49.3	25.6'	5.1	22.7'	19.9	18.4'	-3.2	20.1'	4.0	21.0'	-9.0
37.1	98.8	48.8	10.6	48.7	22.8	44.9	-14.8	36.1	-8.1	47.6	-33.6
55.9	110.2	—	—	—	—	—	—	—	—	—	—
69.3	115.0	69.3	13.0	69.4	20.2	69.4	-22.0	69.4	-27.6	69.3	-44.9

$H'=8.96$				$H'=23.23$				$H'=47.04$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
18.5'	-5.8	25.1'	-17.1	25.8'	-10.2	20.1'	-5.2	16.1'	-2.5	21.2'	-2.5
45.8	-44.9	48.5	-49.4	46.5	-35.1	48.0	-36.8	47.5	-17.0	47.9	-17.8
69.3	-67.2	69.1	-69.4	69.3	-60.2	69.3	-60.8	69.3	-32.6	69.3	-33.2

$H'=92.0$				$H'=208.7$				$H'=367.2$			
τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e	τ	∂I_i	τ	∂I_e
26.2'	-1.5	—	—	25.3'	0.0	—	—	—	—	—	—
48.7	-6.4	—	—	49.5	-1.5	—	—	—	—	—	—
69.3	-13.2	—	—	69.3	-3.0	—	—	69.3	-1.3	—	—

$$T=3366 \text{ gr./mm.}^2, \quad t=12.7^\circ \text{ C.}$$

$H'=0.29$		$H'=0.68$		$H'=0.88$	
τ	∂I_i	τ	∂I_e	τ	∂I_e
23.9'	76.9	23.6'	81.6	23.6'	81.6
49.2	97.6	47.6	139.6	47.5	139.6
69.1	100.9	69.2	143.3	69.2	143.3

$H'=1.68$		$H'=3.06$		$H'=5.00$	
τ	∂I_i	τ	∂I_e	τ	∂I_e
19.8'	27.8	15.8'	0.3	15.2	-3.8
40.4	21.7	33.5	-16.9	31.0	-33.4
—	—	52.6	-35.7	51.5	-48.2
69.2	1.6	69.0	-48.5	69.1	-65.3

$H'=10.75$		$H'=23.43$		$H'=47.06$	
τ	∂I_i	τ	∂I_e	τ	∂I_e
15.4'	-4.7	13.3'	-3.1	13.8'	-2.6
35.1	-27.3	31.3	-23.2	31.3	-23.2
55.5	-52.8	55.1	-53.4	55.1	-53.4
69.1	-67.5	69.1	-68.0	69.1	-68.0

$H'=104.6$		$H'=190.9$		$H'=348.9$	
τ	∂I_i	τ	∂I_e	τ	∂I_e
16.2'	-0.7	15.0'	-0.6	18.4'	-0.3
36.3	-3.3	44.5	-4.4	44.3	-0.7
69.0	-11.2	69.0	-10.1	69.0	-1.7

The effect of giving a maximum twist at once does not materially differ from that of a graded twisting.

(d) *Magnetization under constant twist combined with tensions:* $(I, H)_{\tau, T}$.

The effect of a constant twist on magnetization is comparatively great, especially in high fields. In 28.74% Ni., the magnetization is slightly increased by a small twist, but above a moderate twist, it decreases. In 50.72% Ni., the increase of magnetization by a small twist is not appreciable, but the magnetization always decreases with greater twist. The magnetization of 70.32% Ni., is also decreased by twisting, except in weak fields in which a slight increase is observed. In all cases, the change of magnetization decreases with increasing tension.

In 28.74% Ni., curves $(\partial I, H)_{\tau, T}$ (Fig. 41 in dotted lines) deduced from $(I, H)_{\tau, T}$ show a somewhat different aspect from those deduced from $(\partial I, \tau)_{T, H}$, especially for a small twist. For a small value of twist, ∂I is always positive and have a faint maximum; for a greater twist, it is first negative and afterward positive; and for a still greater twist, it is always negative, and except in weak fields, it takes a course parallel to the corresponding curve obtained from the last experiment, but the former lies somewhat below the latter.

In 50.72% Ni., curves $(\partial I, H)_{\tau, T}$ (Figs. 42 and 43 in dotted lines) deduced from $(I, H)_{\tau, T}$ have a quite different aspect, i.e., ∂I is always negative. It rapidly decreases in weak fields, and after passing through a negative maximum, slopes away very slowly toward the axis of H with increasing field. Tension reduces the decrease of magnetization.

In 70.32% Ni., curves $(\partial I, H)_{\tau, T}$ (Figs. 44, 45, 46 and 47 in dotted lines) deduced from $(I, H)_{\tau, T}$ take a course similar to

those obtained from the last experiment, but the difference is that in the former, the positive maxima in weak fields are considerably smaller, the points at which ∂I changes its sign, lie in a lower part of the field, and ∂I tends more slowly to zero than in the latter. The effect of tension is to push the point of intersections with the axis of H toward the origin.

For these alloys, curves $(\partial I, H)_{\tau, T}$ as deduced from $(I, H)_{\tau, T}$ rather resemble the curves $(\partial I, H)_{\tau, T}$ obtained from the last experiment.

28.74% NICKEL STEEL.

$$T=959 \text{ gr./mm.}^2, \quad t=14.6^\circ \text{ C.}$$

$\tau=0$		$\tau=11.4'$		$\tau=34.8'$		$\tau=68.0'$	
H	I	H	I	H	I	H	I
0.29	35.6	0.28	34.9	0.29	28.1	0.30	23.6
0.42	82.8	0.42	85.5	0.39	77.8	0.44	63.0
0.58	121.8	0.52	112.4	0.57	113.8	0.59	96.6
0.90	165.8	0.85	165.3	0.89	162.2	0.92	137.3
1.34	196.7	1.19	192.9	1.41	197.0	1.64	179.5
2.37	235.3	3.15	261.9	2.89	243.3	2.85	211.9
4.54	271.8	5.35	288.9	4.82	272.6	4.68	238.8
6.91	290.3	6.90	299.6	6.75	286.5	6.89	258.3
18.93	314.5	19.04	322.4	19.04	318.7	19.09	297.8
24.15	318.1	24.30	326.0	24.18	323.1	24.35	303.8
49.20	326.8	50.00	334.9	50.0	332.2	50.1	316.4
129.4	337.7	128.7	346.0	127.3	343.5	126.6	329.0
239.8	350.5	238.8	359.6	236.7	357.2	234.2	342.6
348.5	357.0	366.1	367.5	362.6	364.7	341.5	349.4

50.72% NICKEL STEEL.

 $T=1151 \text{ gr./mm.}^2, \quad t=13.3^\circ \text{ C.}$

$\tau=0$		$\tau=11.7'$		$\tau=34.7'$		$\tau=67.3'$	
H	I	H	I	H	I	H	I
0.18	16.6	0.18	15.8	0.16	13.8	0.18	12.3
0.50	87.8	0.46	92.6	0.50	89.3	0.49	72.6
0.65	197.2	0.66	220.7	0.64	217.3	0.65	182.1
0.79	271.8	0.66	528	0.75	399.5	0.91	480.6
1.14	659	1.08	635	1.10	624	1.18	585
1.43	787	1.37	755	1.45	739	2.02	804
2.73	1016	2.41	981	2.05	882	3.34	929
3.90	1085	4.95	1115	3.56	1013	4.60	994
6.04	1155	8.68	1193	6.42	1112	7.84	1084
12.39	1240	15.43	1251	10.83	1183	14.20	1163
22.58	1288	21.61	1279	22.82	1257	22.45	1215
39.94	1319	40.74	1316	40.30	1297	39.97	1268
100.9	1345	99.9	1346	101.3	1332	101.3	1317
216.9	1354	214.5	1350	217.2	1344	217.2	1334
351.6	1358	349.8	1355	353.7	1348	351.1	1340

 $T=3409 \text{ gr./mm.}^2, \quad t=13.3^\circ \text{ C.}$

$\tau=0$		$\tau=11.7'$		$\tau=68.2'$	
H	I	H	I	H	I
0.21	12.6	0.19	14.4	0.20	26.4
0.49	128.9	0.50	115.6	0.50	127.8
0.61	296.9	0.62	309.6	0.62	330.7
0.90	676	0.79	578	1.02	671
1.13	863	1.02	751	1.37	789
2.43	1073	1.52	932	1.64	859
3.16	1125	2.44	1070	3.22	1031
4.47	1169	5.04	1178	4.34	1077
7.60	1220	8.03	1219	8.08	1151
14.56	1256	13.09	1246	13.51	1193
22.08	1273	22.43	1270	22.61	1229
40.81	1291	40.34	1290	40.67	1264
98.1	1308	97.4	1308	99.2	1300
213.0	1317	209.9	1317	213.7	1315
343.8	1321	340.7	1321	345.9	1317

70.32% NICKEL STEEL.

$$T=1123 \text{ gr./mm.}^2, \quad t=13.0^\circ \text{ C.}$$

$\tau=0$		$\tau=12.7'$		$\tau=35.5'$		$\tau=68.3'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
0.25	23.6	0.20	16.2	0.20	10.0	0.29	17.1
0.74	161.9	0.65	114.4	0.65	144.1	0.63	108.2
0.93	423.4	0.87	302.7	0.91	376.2	0.95	310.2
1.12	575	1.05	555	1.25	672	1.22	689
1.49	688	1.27	635	1.50	701	1.47	713
2.50	809	2.55	790	2.61	774	2.45	764
3.85	890	4.35	883	4.21	834	3.96	809
8.07	988	6.87	939	7.09	888	7.15	858
12.64	1029	10.46	983	11.82	937	11.21	895
17.62	1053	16.66	1020	16.97	970	16.99	930
22.71	1065	21.60	1037	21.86	990	21.93	951
46.73	1090	44.44	1065	44.90	1030	45.18	1005
92.7	1098	87.4	1076	87.1	1047	87.1	1035
181.7	1101	174.6	1080	172.9	1053	172.5	1049
368.1	1104	345.4	1081	342.9	1056	341.2	1055

$$T=3366 \text{ gr./mm.}^2, \quad t=13.0^\circ \text{ C.}$$

$\tau=0$		$\tau=12.8'$		$\tau=36.7'$		$\tau=69.0'$	
<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>	<i>H</i>	<i>I</i>
0.21	9.4	0.21	9.0	0.25	31.4	0.22	6.1
0.56	186.2	0.58	193.6	0.64	232.5	0.67	155.9
0.74	442.9	0.73	436.6	0.71	528	0.72	245.1
0.93	784	0.99	824	0.90	768	0.81	400.8
1.33	863	1.34	866	1.45	839	0.94	767
2.40	934	2.18	924	3.25	912	1.23	800
3.64	973	3.70	972	4.64	936	2.51	863
7.83	1016	7.25	1011	8.37	967	3.75	890
11.86	1035	11.44	1033	12.55	989	9.74	941
16.56	1048	16.81	1047	17.65	1006	17.63	976
21.48	1057	21.78	1056	22.78	1018	22.72	991
44.84	1074	44.83	1074	46.43	1044	46.44	1029
86.7	1081	86.0	1082	89.9	1056	89.9	1051
170.8	1084	171.5	1084	172.2	1062	172.2	1062
359.8	1086	361.8	1086	361.7	1065	364.0	1067

Thus in the case of nickel steels, the change of magnetization by tension does not differ much for the different orders of straining and magnetizing. So also in the change of elasticity, we found a fair agreement between the values for different orders, especially at high tensions. On the other hand, the change of magnetization by twist differs sometimes in a considerable degree for the different orders, while in the change of rigidity, the agreement between the values for different orders is generally good, if the tension be large, especially in 28.74 and 70.32 per cent of nickel. In all, alloys, for which the hysteresis effect is small, have also a small difference in the changes of elastic constants by magnetization for the different orders of magnetizing and straining.

Thus far, we have seen that generally the change of magnetization by stresses differs more or less with the different orders of applying the magnetic field and the stress. In some cases, the difference is not only quantitative but also qualitative, as for the effect of twist in Swedish iron or in 50.72% Ni., if the initial effect of twisting under constant field be compared with the results of magnetization under constant twist. On the other hand, there are examples of good coincidence as in the case of the tension effect in nickel and 70.32% nickel steel. Generally speaking, the tension effect shows a better agreement for the different orders of magnetizing and straining, than for the torsion effect; and the discrepancy is remarkable in low magnetic fields, as may be expected from the consideration of the hysteresis effect prominent in that region.

In our preceding paper, we have remarked, that the dependency of the change of elastic constants on the different orders of magnetizing and straining, is probably due to the hysteresis

effect accompanying magnetization. This explanation agrees well with the facts brought out by the present experiment.

§ 4. RECIPROCAL RELATIONS.

Among several important reciprocal relations obtained by J.J. Thomson, the two relations, which have the connection with the present experiment, are referred to below.

Let a cylindrical bar of soft iron, whose axis coincides with the axis of x , be magnetized along its axis. Let e, f, g , be the dilatations of the bar parallel to the axes of x, y, z respectively; J.J. Thomson obtained the relation

$$n \frac{\partial e}{\partial I^2} = \frac{1}{2} \left\{ 1 - H \left(\frac{\partial z}{\partial I} \right)_{e,f,g} \right\} \left\{ \frac{m}{3m-n} \frac{1}{zI} \left(\frac{\partial I}{\partial e} \right)_{H,f,g} - \frac{m-n}{3m-n} \frac{1}{zI} \left(\frac{\partial I}{\partial f} \right)_{H,e,g} \right\} \dots \dots \dots (1)$$

where I, H, z have the usual meanings, n represents the coefficient of rigidity, and m is connected with the modulus of compression k by the relation $k = m - n/3$. In his original work, the factor $\frac{1}{2}$ is dropped in the right hand member of the above equation: the error is to be traced back to his equation (41).

Since $dI = z dH + H dz$, we have the relation, supposing the strain to be kept constant,

$$1 - H \left(\frac{\partial z}{\partial I} \right)_{e,f,g} = - \frac{z}{\left(\frac{\partial I}{\partial H} \right)_{e,f,g}}.$$

Hence equation (1) may be written

$$\frac{\partial e}{\partial I} \left(\frac{\partial I}{\partial H} \right)_{e,f,g} = \frac{m}{n(3m-n)} \left(\frac{\partial I}{\partial e} \right)_{H,f,g} - \frac{m-n}{n(3m-n)} \left(\frac{\partial I}{\partial f} \right)_{H,e,g} \dots \dots \dots (2)$$

Again if T is the tension per unit of area, we have

$$\begin{aligned} \left(\frac{\partial I}{\partial T}\right)_H &= \left(\frac{\partial I}{\partial c}\right)_{H,f,g} \left(\frac{\partial c}{\partial T}\right)_H + \left(\frac{\partial I}{\partial f}\right)_{H,c,g} \left(\frac{\partial f}{\partial T}\right)_H + \left(\frac{\partial I}{\partial g}\right)_{H,c,f} \left(\frac{\partial g}{\partial T}\right)_H \\ &= \left(\frac{\partial I}{\partial c}\right)_{H,f,g} \left(\frac{\partial c}{\partial T}\right)_H + 2 \left(\frac{\partial I}{\partial f}\right)_{H,c,g} \left(\frac{\partial f}{\partial T}\right)_H, \dots\dots\dots(3) \end{aligned}$$

since we may put $f=g$.

If H is zero, we have

$$\frac{\partial c}{\partial T} = \frac{m}{n(3m-n)} \quad , \quad \frac{\partial f}{\partial T} = -\frac{m-n}{2n(3m-n)} \quad ;$$

hence neglecting the change of elastic constants by magnetization, we have, from (3) ,

$$\left(\frac{\partial I}{\partial T}\right)_H = \frac{m}{n(3m-n)} \left(\frac{\partial I}{\partial c}\right)_{H,f,g} - \frac{m-n}{n(3m-n)} \left(\frac{\partial I}{\partial f}\right)_{H,c,g} \dots\dots\dots(4)$$

Hence by (2) and (4), we get

$$\frac{\partial c}{\partial I} \left(\frac{\partial I}{\partial H}\right)_{c,f,g} = \left(\frac{\partial I}{\partial T}\right)_H$$

$$\begin{aligned} \text{But} \quad \left(\frac{\partial I}{\partial H}\right)_T &= \left(\frac{\partial I}{\partial H}\right)_{c,f,g} + \left(\frac{\partial I}{\partial c}\right)_{H,f,g} \left(\frac{\partial c}{\partial H}\right)_T + \left(\frac{\partial I}{\partial f}\right)_{H,c,g} \left(\frac{\partial f}{\partial H}\right)_T \\ &\quad + \left(\frac{\partial I}{\partial g}\right)_{H,c,f} \left(\frac{\partial g}{\partial H}\right)_T \doteq \left(\frac{\partial I}{\partial H}\right)_{c,f,g} \quad ; \end{aligned}$$

hence finally we get

$$\left(\frac{\partial c}{\partial H}\right)_T = \left(\frac{\partial I}{\partial T}\right)_H \dots\dots\dots(5)$$

As to the twist, J. J. Thomson obtained a relation, which strictly speaking, holds in the case of a thin tube, i. e.

$$n \frac{\partial c}{\partial I^2} = \frac{1}{2ZI} \left(\frac{\partial I}{\partial c}\right)_H \left\{ 1 - H \left(\frac{\partial Z}{\partial I}\right)_c \right\} \quad , \quad \dots\dots\dots(6)$$

Here again in his original work, the factor $\frac{1}{2}$ is dropped: c is not the twist τ per unit length, but it is connected with τ by the

relation $c=r\tau$, where r is the radius of the thin tube. As in the former case, we have

$$1-H\left(\frac{\partial z}{\partial I}\right)_c = \frac{z}{\left(\frac{\partial I}{\partial H}\right)_c} \quad \text{and} \quad \left(\frac{\partial I}{\partial H}\right)_c = \left(\frac{\partial I}{\partial H}\right)_L,$$

in which L is the twisting couple. Equation (6) then becomes

$$\frac{\partial c}{\partial I} \left(\frac{\partial I}{\partial H}\right)_L = \left(\frac{\partial c}{\partial H}\right)_L = \frac{1}{n} \left(\frac{\partial I}{\partial c}\right)_H,$$

$$\text{or, very nearly} \quad r^2 \left(\frac{\partial \tau}{\partial H}\right)_L = \frac{1}{n} \left(\frac{\partial I}{\partial \tau}\right)_H.$$

The last equation, if it be integrated over the cross-section of the wire of radius R gives

$$\frac{\pi}{2} R^4 \left(\frac{\partial \tau}{\partial H}\right)_L = \frac{1}{n} \left(\frac{\partial}{\partial \tau} \int 2\pi r I dr\right)_H = \frac{\pi R^2}{n} \left(\frac{\partial I_m}{\partial \tau}\right)_H,$$

where I_m is the mean intensity of magnetization. Hence

$$\text{finally} \quad \left(\frac{\partial \tau}{\partial H}\right)_L = \frac{2}{nR^2} \left(\frac{\partial I_m}{\partial \tau}\right)_H. \quad \dots\dots\dots(7)$$

From a thermodynamical consideration, A. Heydweiller obtained two relations, neglecting small quantities,

$$\frac{\partial e}{\partial H} = \frac{\partial I}{\partial T} + \frac{I(1-2\sigma)}{E}, \quad \dots\dots\dots(8)$$

$$\frac{1}{E^2} \frac{\partial E}{\partial H} = -\frac{\partial^2 I}{\partial T^2} - \frac{1-2\sigma}{E} \frac{\partial I}{\partial T}, \quad \dots\dots\dots(9)$$

where E is the modulus of elasticity, and σ the Poisson ratio.

In his original paper, σ was put equal to $\frac{1}{3}$. Equation (9) was obtained by differentiating equation (8), considering σ and E to be constant. But in magnetic fields, both σ and E vary considerably with tension, as is shown by our previous experiment, so that if we retain the second term in the right-hand side of

equation (9), the term $I \frac{\partial}{\partial T} \left(\frac{1-2\sigma}{E} \right)$ must be subtracted from it. But these terms being small compared with the first term, they may be neglected without causing any considerable error. The second term in equation (8) is also very small.

On another occasion,* Heydweiller gave relations, which are very nearly equal to the last two with the second terms suppressed, and remarked that they are correct. Heydweiller's equation (8) differs from that given by J. J. Thomson by a term of second importance.

Rensing experimentally tested relation (9) in the case of iron and nickel, and showed a fair agreement between the theory and the experiment.

R. Gans criticized Heydweiller's equations and proposed his own, i. e.,

$$\frac{\partial c}{\partial H} = \frac{1}{4\pi} \frac{\partial B}{\partial T} + \frac{(\mu - \mu_0)}{4\pi E} H \left(\frac{1}{\mu_0} \frac{\partial B}{\partial H} - 2\sigma \right).$$

If the medium surrounding the magnet be air, we may put $\mu_0=1$; hence

$$\frac{\partial c}{\partial H} = \frac{\partial I}{\partial T} + \frac{I(1-2\sigma)}{E} + \frac{2\pi}{E} \frac{\partial I^2}{\partial H} \dots\dots\dots(10)$$

Thus, Gans's equation differs from that of Heydweiller by the term $\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$, which generally is not very small, but in weak fields, it sometimes overweighs the first term. As in the case of Heydweiller, differentiating the above relation with respect to T , Gans obtained an expression for the change of elasticity, which differs from that of Heydweiller by the term $-\frac{2\pi}{E} \frac{\partial^2 I^2}{\partial T \partial H}$. Here again, it was assumed that σ and E are independent of T , a supposition not admissible in a magnetized wire.

* Rensing, loc. cit. p. 377.

By a similar consideration as Heydweiller, A. Koláčák obtained equation (8), and also a relation between magnetism and twist, i. e.,

$$\frac{\partial \tau}{\partial H} = s \frac{\partial I}{\partial L} , \dots\dots\dots(11)$$

where s is the cross section of the wire. Since

$$I = \frac{\pi}{2} R^4 \tau n ,$$

the above equation becomes

$$\frac{\partial \tau}{\partial H} = \frac{2}{n R^2} \cdot \frac{\partial I}{\partial \tau} , \dots\dots\dots(12)$$

which coincides with equation (9).

M. Cantone obtained two relations by equating the change of magnetic energy due to a tension or a twist to the change of elastic energy caused by magnetization, i. e. ,

$$e_m = \frac{\partial}{\partial T} \int_0^L H dI \text{ and } \tau_m = s \frac{\partial}{\partial L} \int_0^L H dI ,$$

where e_m and τ_m are the magnetic strains. By differentiating the above equations with respect to H , we have

$$\frac{\partial e}{\partial H} = \frac{\partial}{\partial T} \left(H \frac{\partial I}{\partial H} \right) , \dots\dots\dots(13)$$

$$\frac{\partial \tau}{\partial H} = s \frac{\partial}{\partial L} \left(H \frac{\partial I}{\partial H} \right) . \dots\dots\dots(14)$$

Cantone tested the second relation by experiment and found a satisfactory agreement in iron and nickel. For the first relation, he also made a comparison between theory and experiment, but the data he used were taken from experiments by different physicists, so that they do not refer to the same specimen. Though the comparison shows a satisfactory agreement, it is not certain, whether it was by chance or not.

By a direct method, Dr. Sano obtained the relation

$$\frac{\partial e}{\partial H} = \frac{\partial I}{\partial T} + \frac{I(1-2\sigma)}{E} + \frac{2\pi}{E} \frac{\partial(z_0^2 H^2)}{\partial H}, \dots\dots\dots(15)$$

where z_0 is a term in the expression of susceptibility, which is independent of the strain. Since $I \doteq z_0 H$, Sano's equation practically coincides with Gans's. For the change of elasticity, Dr. Sano obtained

$$\frac{1}{E^2} \frac{\partial E}{\partial H} = - \frac{\partial^2 I}{\partial T^2}, \dots\dots\dots(16)$$

which is practically the same as Heydweiller's equation, but different from Gans's by a term not negligibly small in weak fields. The above equation was obtained independently of the relation for $\frac{\partial e}{\partial H}$. As to the effect of twist, Dr. Sano obtained an equation, which can be transformed into (12).

Thus far, the relations for $\frac{\partial e}{\partial H}$ given by Heydweiller, Gans, Koláčêk and Sano all agree with one another in the first important term $\frac{\partial I}{\partial T}$. Relation (1) given by J.J. Thomson does not differ in reality from others. Relation (13) given by Cantone also coincides with others in the first term, provided z is independent of H . The second term $I(1-2\sigma)/E$ in (8) and (10) may be neglected for the first approximation; the third term in relation (10), which becomes important in weak fields is properly to be added.

The relations for $\frac{\partial E}{\partial H}$ given by Heydweiller, Gans and Sano also agree with each other in the first term $-\frac{\partial^2 I}{\partial T^2}$. Gans's differs principally from the others by a term not generally small in weak fields.

As regards the relation for $\frac{\partial \tau}{\partial H}$, Koláčêk's and Sano's coincide with each other. Thomson's relation (6) also does not differ

from the others. If z be independent of H , Cantone's formula coincides with the others.

Thus, the chief relations to be tested by experiments are as follows :—

$$\frac{\partial e}{\partial H} = \frac{\partial I}{\partial H} + \frac{2\pi}{E} \frac{\partial I^2}{\partial H},$$

$$\frac{1}{E^2} \frac{\partial E}{\partial H} = - \frac{\partial^2 I}{\partial T^2},$$

$$\frac{\partial \tau}{\partial H} = \frac{2}{nR^2} \frac{\partial I}{\partial \tau} = s \frac{\partial I}{\partial L}.$$

Our present experiments combined with the previous investigations on the change of elastic property due to magnetization furnish us with good materials for the testing of these relations.

Our results taken as a whole, give for the effect of tension as well as of twist, two different sets of experimental data corresponding to the different orders of applying the magnetic field and the stress. The mutual correspondence of the results in the previous and the present experiments in this respect is tabulated below :

*Change of Strains by
Magnetization.*

1. Magnetic elongation under constant tension.

Elongation by tension under constant field.

2. Magnetic twisting under constant couple (Barus's method).

Change of rigidity under constant field (oscillation method).

*Change of Magnetization by
Strain.*

1.' Magnetization under constant tension.

Change of magnetization by tension under constant field.

2.' Magnetization under constant twist.

Change of magnetization by twist under constant field.

The theoretical relations to be tested were, however, deduced on the supposition that the magnetization is independent of the order of magnetizing and straining, so that in comparing the theory and the experiment, too much weight is not to be placed on the above correspondence.

The values of $\frac{\partial e}{\partial H}$, $\frac{\partial E}{\partial H}$ and $\frac{\partial \tau}{\partial H}$ were deduced from our previous experiment, while the corresponding values for $\frac{\partial I}{\partial T}$, $\frac{\partial^2 I}{\partial T^2}$ and $\frac{\partial I}{\partial L}$ were obtained from the present experiment. In the following tables, $\left[\frac{\partial I}{\partial T}\right]_H$ and $\left[\frac{\partial^2 I}{\partial T^2}\right]_H$ are the values of these differential coefficients obtained from curves $(\partial I, T)_H$; while $\left[\frac{\partial I}{\partial T}\right]_T$ and $\left[\frac{\partial^2 I}{\partial T^2}\right]_T$ are the values of the coefficients from curves $(I, H)_T$. $\frac{1}{E^2}\left[\frac{\partial E}{\partial H}\right]_H$ is the value obtained from the results of the elongation method; while $\frac{1}{E^2}\left[\frac{\partial E}{\partial H}\right]_T$ is that obtained from the tension effect on magnetic elongation. $\frac{1}{\tau}\left[\frac{\partial \tau}{\partial H}\right]_H$ is the value of the coefficient obtained from the result of the oscillation method, and $\frac{1}{\tau}\left[\frac{\partial \tau}{\partial H}\right]_T$ that obtained from the Barus's method; while $\frac{s}{\tau}\left[\frac{\partial I}{\partial L}\right]_H$ and $\frac{s}{\tau}\left[\frac{\partial I}{\partial L}\right]_T$ are the values obtained from curves $(\partial I, \tau)_H$ and $(I, H)_T$ respectively. To find the values of these differential coefficients, corresponding curves were carefully drawn on section papers; a fine straight line drawn on a thin glass plate was brought into contact with the curve at the required point and the trigonometrical tangent of the inclination of this straight line was evaluated.

SWEDISH IRON.

H	$T=1627 \text{ gr./mm.}^2$				$T=2410 \text{ gr./mm.}^2$			$T=5535 \text{ gr./mm.}^2$		
	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$
Measured in 10^{-8}										
5.9	+18	+72	+63	+33	+16	+57	+46	+1.0	+20	+0.0
11.9	+14	+13	+12	+14	+8.0	+11	+10	+0.7	+2.0	+0.0
24.2	+0.8	+0.6	+3.3	+4.7	+0.5	+0.2	+3.1	-1.0	-0.8	-7.0
36.6	-0.7	-1.7	+2.0	+2.7	-0.8	-1.7	+0.0	-1.7	-1.9	-6.2
97.1	-1.8	-2.4	—	+1.2	-1.8	-2.4	+0.0	-2.1	-2.0	-5.0
207	-2.0	-2.2	—	+0.7	-2.0	-2.2	+0.0	-1.9	-2.3	-8.0
367	-1.4	-1.7	—	+0.4	-1.4	-1.7	+0.0	-1.4	-1.9	—

H	$T=1627 \text{ gr./mm.}^2$				$T=3190 \text{ gr./mm.}^2$			$T=4754 \text{ gr./mm.}^2$		
	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2} \right]_H$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$
Measured in 10^{-17}										
5.9	—	-54	—	—	-30	—	—	-19	—	—
11.9	0.0	-28	-29	-26	-21	-29	-20	-19	-29	-41
24.2	-0.39	-11	-7.1	—	-6.4	-4.5	-21	-8.8	-2.8	—
36.6	-0.61	-4.6	—	-22	-3.3	-1.8	-31	-3.3	-1.0	-12
97.1	-1.23	+0.03	—	—	-0.53	+1.0	-13	+0.05	—	—
207	-0.20	+0.84	—	—	+0.03	+0.28	-18	+0.03	-0.6	-34
367	-0.06	+0.64	—	—	+0.21	-0.28	—	+0.00	-0.3	—

 $T=3255 \text{ gr./mm.}^2$

H	$\tau=6.3'$		$\tau=6.3'$		$\tau=6'.3$		$\tau=58'.0$	
	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_T$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_T$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_T$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_T$
Measured in 10^{-4}								
4	—	—	-11	+128	+64	—	-16	—
6	—	—	-13	+92	-8.0	—	-12	—
8	—	—	-11	+48	-4.8	—	-8.6	—
14	+0.23	-3.6	+24	—	-1.6	—	-6.2	—
22	-0.15	-2.7	+12	—	—	—	-4.8	—
50	-0.40	-1.1	+30	—	—	—	-0.96	—
110	-0.40	-0.3	+0.7	—	—	—	-0.48	—
200	+0.12	-0.11	+0.0	—	—	—	-0.48	—
300	+0.07	-0.07	—	—	—	—	-0.24	—

TUNGSTEN STEEL.

H	$T=1693 \text{ gr./mm.}^2$				$T=3322 \text{ gr./mm.}^2$				$T=5762 \text{ gr./mm.}^2$			
	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$		
Measured in 10^{-5}												
10.6	+0.9	+3.3	+0.0	+0.65	+0.9	+3.3	+0.0	+0.7	+4.6	+0.0		
23.9	+1.2	+23.0	+2.4	+20.6	+1.1	+22	+17	+0.5	+18	+13		
43.4	+3.4	+4.3	+0.0	+4.8	+3.2	+5.4	+0.0	+5.5	+4.4	+0.0		
98.4	+0.57	+0.38	-2.9	+1.2	+0.62	+0.40	-2.9	+0.35	+0.40	-5.0		
210	-0.10	-0.32	-3.0	+0.50	-0.17	-0.37	-4.2	-0.25	-0.35	-3.6		
341	-0.25	-0.32	-3.1	+0.23	-0.21	-0.38	-3.1	-0.29	-0.36	-3.6		

H	$T=1692 \text{ gr./mm.}^2$				$T=4947 \text{ gr./mm.}^2$			
	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H} \right]_H$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H} \right]_H$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$
Measured in 10^{-17}								
23.9	-0.10	-0.81	-3.2	-52	-3.6	-4.1	-18	-43
43.4	-0.10	-0.90	+8.3	0.0	-2.1	-3.5	-6.2	0.0
98.4	-0.16	-1.20	0.0	0.0	-1.8	-0.83	-0.0	+1.2
210	-0.26	-0.67	0.0	0.0	-0.0	-0.32	-0.0	+4.2
341	-0.05	-0.0	0.0	0.0	+0.41	-0.17	-0.0	+0.0

 $T=3340 \text{ gr./mm.}^2$

H	$\tau=20.0'$		$\tau=20.0'$		$\tau=37.6'$	
	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_\tau$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_\tau$		
Measured in 10^{-1}						
10.7	+0.23	—	+1.5	—		
18.4	+0.10	-1.0	+7.9	+1.0		
30.1	-0.04	-0.53	+3.2	-0.35		
98.8	-0.03	-0.15	+0.3	-0.57		
364	-0.03	-0.03	-0.04	-0.52		

NICKEL.

H	$T=1540 \text{ gr./mm.}^2$				$T=2283 \text{ gr./mm.}^2$				$T=5240 \text{ gr./mm.}^2$			
	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$		$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	
Measured in 10^{-7}												
10.8	-5.3	-3.7	-5.1	+0.12	-4.0	-3.8	-5.1		-0.40	-2.2	-3.9	
31.1	-7.7	-3.7	-4.9	+0.11	-5.4	-4.2	-5.4		-1.8	-3.8	-3.2	
62.5	-2.2	-2.2	-2.8	+0.06	-3.1	-2.6	-4.3		-3.1	-3.5	-3.1	
135	-0.68	-0.71	-0.66	+0.02	-0.74	-0.78	-1.7		-2.0	-1.6	-1.8	
206	-0.32	-0.32	-0.38	+0.01	-0.28	-0.38	-1.1		-0.80	-0.72	-1.1	
365	-0.05	-0.05	-0.05	+0.00	-0.11	-0.05	-0.64		-0.17	-0.17	-0.3	

H	$T=3021 \text{ gr./mm.}^2$				$T=4498 \text{ gr./mm.}^2$			
	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H}\right]_H$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H}\right]_T$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_H$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_T$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H}\right]_H$	$\frac{1}{E^2} \left[\frac{\partial E}{\partial H}\right]_T$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_H$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_T$
Measured in 10^{-16}								
10.8	+4.7	+4.7	+1.0	+10.6	+2.3	+2.3	+2.0	+0.0
31.7	+10.0	+10.1	+0.79	—	+3.7	+4.2	+8.9	+15.3
62.5	+12.2	+14.0	-4.0	+3.1	+7.6	+13.7	-2.6	+7.3
135	-2.7	-3.0	-2.1	-5.1	-3.3	-5.2	-3.6	+4.1
206	-0.67	-0.7	-1.6	-2.3	-1.2	-1.3	-0.85	+3.4
365	-0.28	-0.3	-0.41	-1.6	-0.44	-0.55	-0.39	+5.1

T	$T_m=1143 \text{ gr./mm.}^2$				$T_m=3400 \text{ gr./mm.}^2$			
	1153 gr.	1022 gr.	1197 gr.	1197 gr.	3410 gr.	3096 gr.	3546 gr.	3546 gr.
$\tau'=12.6'$								
H	$\frac{1}{E} \left[\frac{\partial \tau}{\partial H}\right]_H$	$\frac{1}{E} \left[\frac{\partial \tau}{\partial H}\right]_T$	$\frac{1}{E} \left[\frac{\partial I}{\partial T}\right]_H$	$\frac{1}{E} \left[\frac{\partial I}{\partial T}\right]_T$	$\frac{1}{E} \left[\frac{\partial \tau}{\partial H}\right]_H$	$\frac{1}{E} \left[\frac{\partial \tau}{\partial H}\right]_T$	$\frac{1}{E} \left[\frac{\partial I}{\partial T}\right]_H$	$\frac{1}{E} \left[\frac{\partial I}{\partial T}\right]_T$
Measured in 10^{-23}								
2.4	+0.83	-0.72	+7.4	—	+0.20	-1.4	+1.9	—
4.0	+1.56	-3.2	+6.1	+0.87	+0.27	-3.4	+3.6	+0.33
10.6	+1.80	+2.3	+3.5	+2.0	+0.50	+2.5	+3.5	+3.5
23.8	+1.60	+0.84	+1.1	+0.52	+1.28	+3.5	+1.9	+1.8
49.6	+0.14	-0.37	-0.44	-0.57	+1.24	+0.4	+0.7	+0.96
97.0	-0.22	-0.60	-0.33	-0.78	-0.02	-0.48	-0.78	-0.39
168	-0.34	-0.40	-0.17	-0.70	-0.20	-0.50	-0.17	-0.26
358	-0.18	-0.17	-0.00	-0.52	-0.20	-0.20	-0.05	—

28.74% NICKEL STEEL.

$T=1427 \text{ gr./mm.}^2$				$T=2798 \text{ gr./mm.}^2$				$T=4856 \text{ gr./mm.}^2$		
H	$\frac{\partial \epsilon}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial \rho}{\partial I}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$	$\frac{\partial \rho}{\partial H}$	$\left[\frac{\partial I}{\partial T}\right]_H$	$\left[\frac{\partial I}{\partial T}\right]_T$
Measured in 10^{-8}										
4.7	8.0	11	25	2.1	4.4	4.0	14	2.2	2.4	4.1
10.6	3.0	2.2	16	0.4	1.8	1.3	12	1.2	1.6	2.9
24.3	1.3	1.6	17	0.2	1.1	1.3	12	1.0	1.2	2.6
55.5	1.0	1.3	16	0.04	0.9	1.2	12	1.0	1.1	2.6
173	1.0	1.2	15	0.03	1.0	1.1	11	0.9	1.1	3.1
374	1.0	1.0	15	0.00	1.0	1.0	11	0.9	1.0	3.4

H	$T=1427 \text{ gr./mm.}^2$				$T=4170 \text{ gr./mm.}^2$			
	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2}\right]_H$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2}\right]_T$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_H$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_T$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2}\right]_H$	$\frac{1}{E^2} \left[\frac{\partial^2 I}{\partial H^2}\right]_T$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_H$	$\left[\frac{\partial^2 I}{\partial T^2}\right]_T$
Measured in 10^{-17}								
4.7	-6.1	-13	-111	—	-4.1	-3.0	-1.5	—
10.6	-4.0	-8.9	-7.9	-26	-3.0	-2.6	—	-51
24.3	-2.0	-4.8	-2.6	—	-1.6	-1.6	-0.3	—
55.5	-0.4	-1.8	-1.8	—	-0.2	-0.3	-0.1	—
374	-0.0	+0.1	-0.0	-17	-0.2	+0.1	-0.0	-51

T	$T_m=950 \text{ gr./mm.}^2$							
	928 gr.	948 gr.	940 gr.	943 gr.	959 gr.	953 gr.	953 gr.	959 gr.
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H}\right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H}\right]_T$			$\frac{s}{\tau} \left[\frac{\partial I}{\partial L}\right]_H$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L}\right]_T$	
		$\tau=6.4'$	$\tau=12.7'$	$\tau=19.1'$	$\tau=6.4'$	$\tau=12.7'$	$\tau=19.1'$	$\tau=38.2'$
Measured in 10^{-4}								
1.9	—	-2.5	-3.5	-3.0	-2.5	-2.4	-2.8	-2.7
6.7	-1.5	-3.4	-2.8	-2.4	-6.1	-4.6	-3.6	-3.2
14.5	-0.6	-1.0	-1.0	-0.9	-2.3	-2.0	-1.7	-2.4
30.5	-0.5	-0.35	-0.28	-0.33	-0.62	-0.8	-0.54	-2.1
61	-0.2	-0.23	-0.04	-0.07	-0.20	-0.20	-0.20	-2.1
303	+0.03	+0.02	-0.00	-0.00	-0.00	-0.0	-0.00	-1.7

T	$T_m=4200 \text{ gr./mm.}^2$					
	4096 gr.	4240 gr.	4240 gr.	4211 gr.	4211 gr.	
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_{\tau}$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$		
		$\tau=8.9'$	$\tau=19.1'$	$\tau=8.9'$	$\tau=19.1'$	
	Measured in 10^{-4}					
3.6	-1.2	-3.0	-2.9	-4.5	-3.9	
6.8	-1.3	-2.2	-2.0	-3.2	-2.0	
14.8	-0.95	-0.50	-0.65	-1.2	-0.96	
35.6	-0.25	-0.20	-0.17	-0.44	-0.31	
66.7	-0.15	-0.10	-0.03	-0.00	-0.00	
300	-0.00	-0.00	-0.00	-0.00	-0.00	

50.72% NICKEL STEEL.

H	$T=890 \text{ gr./mm.}^2$				$T=2538 \text{ gr./mm.}^2$				$T^*=6652 \text{ gr./mm.}^2$		
	$\frac{\partial e}{\partial H}$	$\frac{\partial I}{\partial T}_H$	$\frac{\partial I}{\partial T}_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial e}{\partial H}$	$\frac{\partial I}{\partial T}_H$	$\frac{\partial I}{\partial T}_T$		$\frac{\partial e}{\partial H}$	$\frac{\partial I}{\partial T}_H$	$\frac{\partial I}{\partial T}_T$
	Measured in 10^{-7}										
1.9	11.9	20	9.0	11.2	5.3	4.8	4.7	-0.62	-0.16	-0.78	
5.5	6.3	8.2	7.1	2.2	2.4	2.7	3.6	-0.83	-0.16	-0.42	
10.7	3.7	5.7	4.0	1.0	1.3	1.5	2.4	-0.25	-0.08	-0.57	
23.8	1.7	2.2	1.9	0.1	0.48	0.56	1.3	-0.09	-0.05	-0.51	
51.4	0.34	0.61	0.70	0.07	0.13	0.15	0.73	-0.05	-0.02	-0.51	
151	0.04	0.03	0.32	0.01	0.02	0.02	0.42	-0.01	-0.01	-0.51	
360	0.03	0.00	0.25	0.01	0.01	0.00	0.28	-0.00	-0.00	-0.36	

H	$T=890 \text{ gr./mm.}^2$				$T=5003 \text{ gr./mm.}^2$			
	$\frac{1}{E^2} \left[\frac{\partial I^2}{\partial H} \right]_H$	$\frac{1}{E^2} \left[\frac{\partial I^2}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$	$\frac{1}{E^2} \left[\frac{\partial I^2}{\partial H} \right]_H$	$\frac{1}{E^2} \left[\frac{\partial I^2}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$
	Measured in 10^{-7}							
5.5	-1.5	-1.5	-7.5	-1.9	-0.19	-0.20	-0.51	-0.66
10.7	-1.9	-1.9	-3.4	-0.62	-0.13	-0.15	-0.10	-0.56
23.8	-0.58	-0.79	-1.4	-0.21	-0.10	-0.09	-0.10	-0.36
51.4	-0.08	-0.27	-0.41	-0.03	-0.04	-0.03	-0.00	-0.41
151.0	-0.02	-0.02	-0.03	-0.01	-0.01	-0.01	-0.00	-0.34
360	-0.01	-0.01	-0.00	+0.00	-0.00	-0.00	-0.00	-0.23

* Under a high tension, this specimen slightly contracts by magnetization, which is also to be expected from the effect of tension on magnetization.

T	$T_m = 1140 \text{ gr./mm.}^2$					
	1114 gr.	1136 gr.	1136 gr.	1151 gr.	1151 gr.	1151 gr.
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_T$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_T$
		$\tau = 6.2'$	$\tau = 18.6'$	$\tau = 6.2'$	$\tau' = 52.3'$	$\tau = 18.6'$
	Measured in 10^{-3}					
5.5	-0.0	-2.4	-2.4	+8.7	-1.5	-2.5
12.6	-1.8	-2.2	-1.0	+5.1	-1.3	-2.3
24.5	-1.2	-1.2	-1.2	+3.3	-0.86	-1.6
49.6	-0.60	-0.65	-0.64	+1.4	-0.41	-0.72
109	-0.17	-0.20	-0.20	+0.54	-0.09	-0.45
212	-0.07	-0.06	-0.06	+0.22	-0.07	-0.36
377	-0.02	-0.05	-0.05	+0.00	-0.00	-0.00

T	$T_m = 3400 \text{ gr./mm.}^2$					
	3277 gr.	3445 gr.	3445 gr.	3493 gr.	3493 gr.	3400 gr.
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_T$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$		$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_T$
		$\tau = 6.2'$	$\tau = 18.6'$	$\tau = 6.2'$	$\tau = 52.3'$	$\tau = 17.4'$
	Measured in 10^{-3}					
4.2	-1.5	-1.8	-1.8	+9.1	-1.2	-1.6
10.5	-1.8	-1.7	-1.4	+5.0	-1.1	-1.5
24.5	-0.95	-1.0	-0.90	+2.4	-0.69	-0.73
49.6	-0.42	-0.47	-0.47	+1.3	-0.35	-0.44
109.0	-0.17	-0.17	-0.17	+0.48	-0.13	-0.12
212	-0.07	-0.05	-0.05	+0.09	-0.04	-0.00
377	-0.02	-0.02	-0.02	+0.00	-0.00	-0.00

70.32% NICKEL STEEL.

H	$T = 806 \text{ gr./mm.}^2$				$T = 1671 \text{ gr./mm.}^2$				$T = 3277 \text{ gr./mm.}^2$		
	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T} \right]_H$	$\left[\frac{\partial I}{\partial T} \right]_T$	$\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$	$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T} \right]_H$	$\left[\frac{\partial I}{\partial T} \right]_T$		$\frac{\partial e}{\partial H}$	$\left[\frac{\partial I}{\partial T} \right]_H$	$\left[\frac{\partial I}{\partial T} \right]_T$
	Measured in 10^{-7}										
1.5	19	27	20	11	12	13	14		3.8	5.1	4.9
2.7	11	14	12	3.7	6.0	8.7	9.4		2.3	4.6	3.7
5.1	6.2	7.1	9.2	1.9	4.1	5.1	4.3		1.6	2.4	2.6
10.7	1.7	3.6	4.1	0.56	2.2	3.1	2.3		0.89	1.0	1.0
24.5	0.4	0.6	3.1	0.13	0.33	0.6	0.5		0.17	0.3	0.0
49.8	0.09	0.20	2.6	0.03	0.07	0.2	0.0		0.03	0.1	0.0
129	0.01	0.03	2.0	0.00	0.01	0.03	0.0		0.01	0.00	0.0
300	0.01	0.00	2.0	0.00	0.01	0.00	0.0		0.00	0.00	0.0

H	$T=1671 \text{ gr./mm.}^2$				$T=3277 \text{ gr./mm.}^2$			
	$\frac{1}{-E^2} \left[\frac{\partial E}{\partial H} \right]_H$	$\frac{1}{-E^2} \left[\frac{\partial E}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$	$\frac{1}{-E^2} \left[\frac{\partial E}{\partial H} \right]_H$	$\frac{1}{-E^2} \left[\frac{\partial E}{\partial H} \right]_T$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_H$	$\left[\frac{\partial^2 I}{\partial T^2} \right]_T$
	Measured in 10^{-16}							
5.1	-10.4	-28	-19	-26	-7.2	-6.7	-14.6	-6.1
10.7	-3.0	-3.9	-8.7	-1.4	-2.3	-1.6	-15.3	-6.3
21.5	-0.93	-1.2	-0.61	-7.6	-0.77	-0.70	-0.5	-1.6
49.8	-0.30	-0.39	-0.00	-0.6	-0.08	-0.10	-0.0	-0.0
129	-0.10	-0.03	-0.00	-0.0	-0.02	-0.02	-0.0	—
300	-0.03	-0.01	-0.00	-0.0	-0.00	-0.00	-0.0	—

T	$T_m=1112 \text{ gr./mm.}^2$					
	1086 gr.	1109 gr.	1109 gr.	1123 gr.	1123 gr.	1123 gr.
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_{\tau}$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_{\tau}$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_{\tau}$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_{\tau}$
		$\tau=12.2'$	$\tau=18.2'$	$\tau=12.2'$	$\tau=18.2'$	$\tau=46.0'$
	Measured in 10^{-1}					
3.1	-1.4	-1.1	-1.1	+1.3	+0.65	+1.1
4.6	-2.0	-1.9	-1.4	+0.13	+0.19	+0.42
8.9	-2.6	-2.3	-1.8	-0.30	-0.87	-0.14
23.2	-1.4	-1.2	-1.0	-0.63	-0.51	-0.36
47.2	-0.50	-0.44	-0.41	-0.53	-0.31	-0.42
92.0	-0.16	-0.19	-0.16	-0.07	-0.09	-0.42
209	-0.04	-0.03	-0.04	-0.00	-0.00	-0.28
367	-0.02	-0.03	-0.02	-0.00	-0.00	-0.07

T	$T_m=3336 \text{ gr./mm.}^2$					
	3193 gr.	3361 gr.	3361 gr.	3366 gr.	3366 gr.	3366 gr.
H	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_H$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_{\tau}$	$\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H} \right]_{\tau}$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_H$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_{\tau}$	$\frac{s}{\tau} \left[\frac{\partial I}{\partial L} \right]_{\tau}$
		$\tau=11.8'$	$\tau=18.0'$	$\tau=11.8'$	$\tau=18.0'$	$\tau=34.5'$
	Measured in 10^{-3}					
3.1	-2.4	-1.8	-1.4	-0.35	-0.70	-1.1
5.0	-2.8	-2.0	-1.2	-0.83	-1.4	-1.0
10.7	-1.3	-1.5	-1.2	-0.76	-0.79	-0.95
23.4	-0.76	-0.84	-0.72	-0.52	-0.48	-0.67
47.2	-0.32	-0.33	-0.32	-0.17	-0.18	-0.56
105	-0.12	-0.10	-0.10	-0.04	-0.07	-0.53
191	-0.04	-0.03	-0.02	-0.00	-0.02	-0.53
319	-0.01	-0.01	-0.01	-0.00	-0.00	-0.53

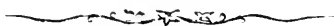
Among all the specimens tested, nickel affords the best evidence in favour of the theories above tested. The discrepancies due to the difference of the orders of applying the stress and the field, are generally small, when compared with those in the case of other specimens. The agreement is especially good in the case of tension effect, if the term $\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$ be suppressed; the difference between the values $\frac{\partial e}{\partial H}$ and $\frac{\partial I}{\partial T}$ is of such orders of magnitude that they may be explained by the errors introduced in estimating these values from the corresponding diagrams. For the rest of the specimens, the agreement is tolerably good in many cases, except a few cases in which it completely fails. Generally speaking, the tension effect shows a better agreement between theory and experiment, if $\frac{\partial e}{\partial H}$ be compared with $\left[\frac{\partial I}{\partial T}\right]_H$; while $\left[\frac{\partial I}{\partial T}\right]_T$ deduced from the $(I, H)_T$ curve is often of a different order of magnitude, as in the case of 28.74% Ni. As for the comparison between $-\frac{1}{E^2} \frac{\partial E}{\partial H}$ and $\left[\frac{\partial^2 I}{\partial T^2}\right]_H$, the agreement is less remarkable, but the discrepancies may in many cases be due to the errors introduced in estimating the curvature of the curves for obtaining $\left[\frac{\partial^2 I}{\partial T^2}\right]_H$. $\left[\frac{\partial^2 I}{\partial T^2}\right]_T$ deduced from $(I, H)_T$ curve is often of a different order of magnitude, as in the case of Swedish iron. For torsion effect, things are much more complicated, except in the case of nickel and nickel steels of 28.74 and 70.32 per cent of nickel, in which the agreement is fairly good. For the last two specimens, $\frac{s}{\tau} \left[\frac{\partial I}{\partial L}\right]_H$ generally agrees with $\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H}\right]_H$ or $\frac{1}{\tau} \left[\frac{\partial \tau}{\partial H}\right]_T$, while in the case of 50.72% Ni., the former is of a different sign from the latter for small twist. In all cases, the discrepancies become less in high fields.

As to the term $-\frac{2\pi}{E} \frac{\partial I^2}{\partial H}$ obtained by Gans and Sano, it may be noticed that its introduction makes the agreement between

theory and experiment rather worse. The origin of this term is, however, to be traced to the fundamental assumption that at the ends of the specimen wire, the lines of induction issue normally from its end faces—an assumption far from being realized in our actual experiments. Hence the importance of this term must be reduced, when applied to the case usually subject to experiments.

Thus far, the agreement between theory and experiment is in general to be considered as fairly good, if we consider the difficulties encountered in measuring the minute strains caused by magnetization, and also the considerable dependence of the magnetization upon the order of magnetizing and straining. Since the theories, which are based upon quite different considerations, all agree with one another in the first important term, it may be concluded that for the first approximation, they are all verified by the present experiment. It seems however impossible to decide experimentally the correctness of the terms of second importance for ferromagnetic substances, in which the hysteresis effect appears in no inconsiderable amount.

In conclusion, we wish to express our best thanks to Dr. S. SANO for useful suggestions in working out the theoretical part of the present investigation.



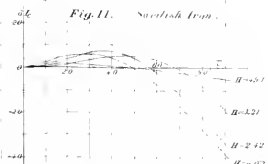
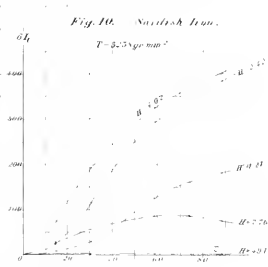
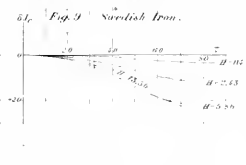
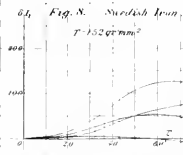
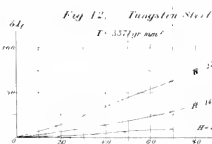
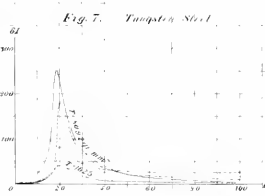
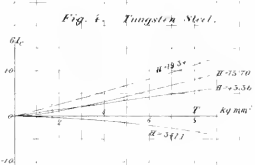
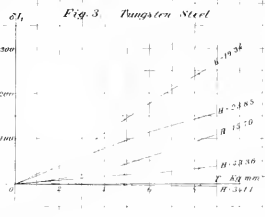
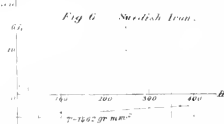
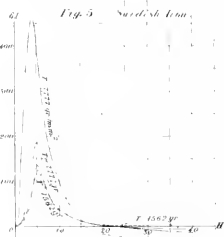
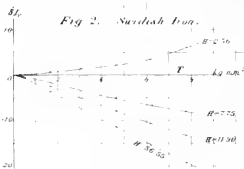
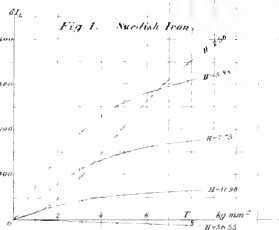


Fig. 13. Swedish Iron.

$$T = 15.2 \text{ gr mm}^2$$

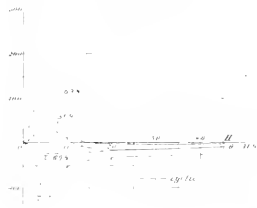


Fig. 14. Swedish Iron.

$$T = 15.2 \text{ gr mm}^2$$

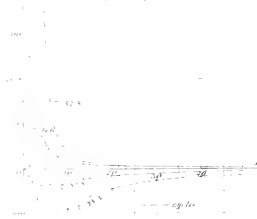


Fig. 15. Tungsten Steel.

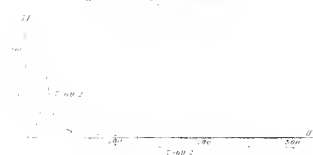


Fig. 16. Nickel.

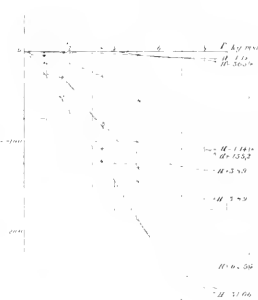


Fig. 17. Nickel.

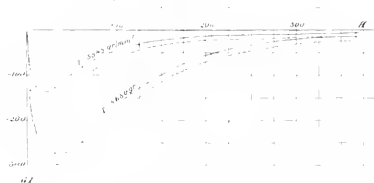


Fig. 18. Nickel.

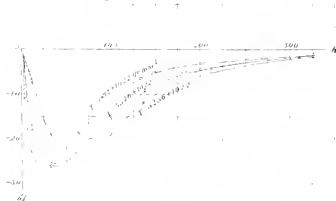


Fig. 19. Nickel.

$$T = 11.92 \text{ gr mm}^2$$

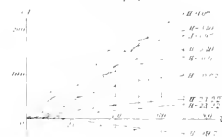


Fig. 20. Nickel.

$$T = 24.6 \text{ gr mm}^2$$



Fig. 21. Nickel.

$$T = 11.92 \text{ gr mm}^2$$

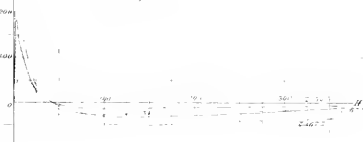


Fig. 22. Nickel.

$$T = 6.2 \text{ Me gr mm}^2$$



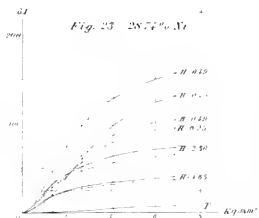
Fig. 23 28.74% Nt 

Fig. 27. 50-72% N_2 .

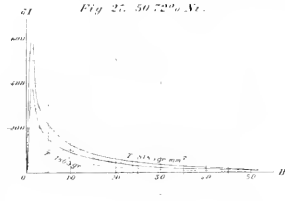


Fig. 26. 28.74% Ni.

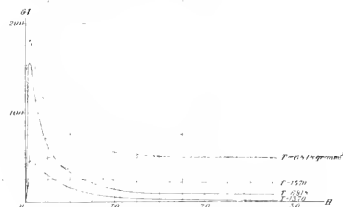


Fig. 24. 50.72% Ni.

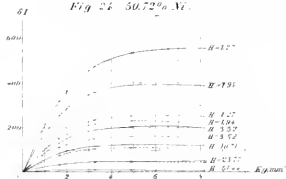


Fig. 25. 70-32% Ni.

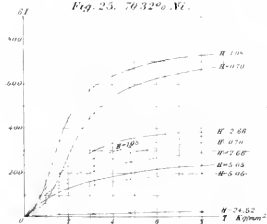


Fig. 29

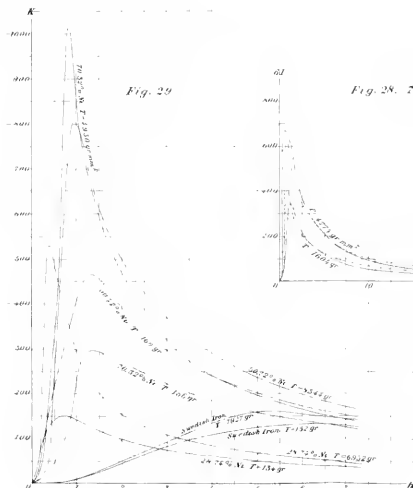


Fig. 28. 70.32% Ni.

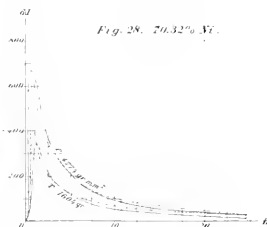


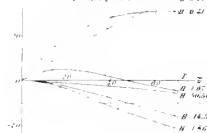
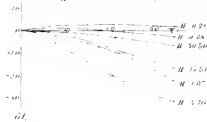
Fig. 30. $28.74^{\circ} \text{u. } \Delta T$.
 $T = 9.5 \text{ gr. mm}^2$

 Fig. 31. $28.74^{\circ} \text{u. } \Delta T$

 Fig. 32. $28.72^{\circ} \text{u. } \Delta T$.

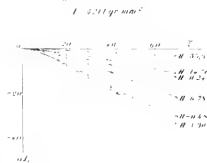
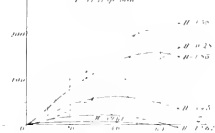
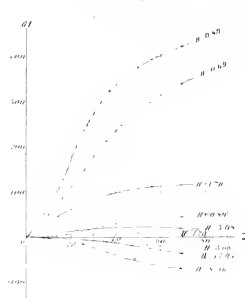
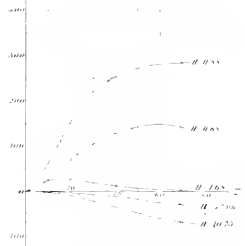
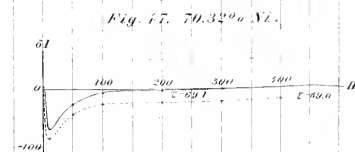
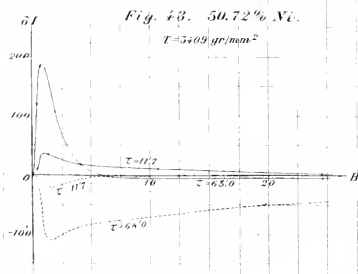
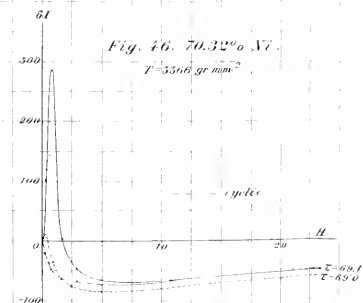
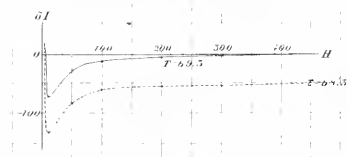
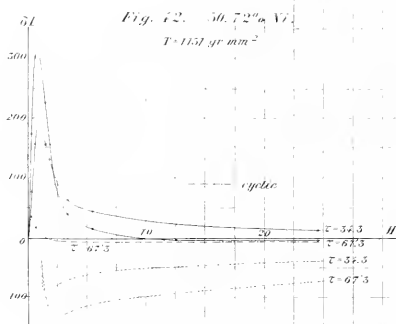
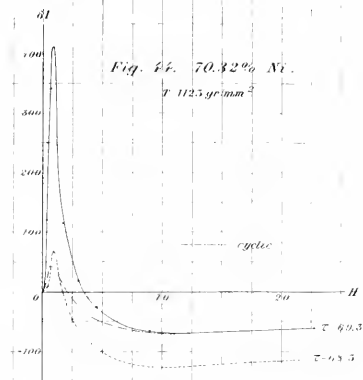
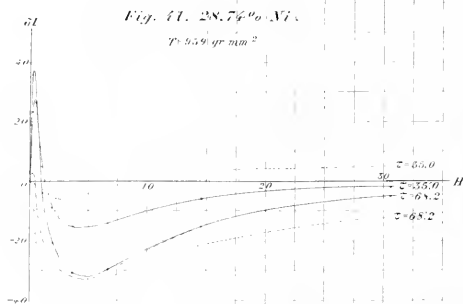
 Fig. 33. $28.74^{\circ} \text{u. } \Delta T$.

 Fig. 34. $50.72^{\circ} \text{u. } \Delta T$.
 $T = 11.1 \text{ gr. mm}^2$

 Fig. 35. $50.72^{\circ} \text{u. } \Delta T$

 Fig. 36. $50.72^{\circ} \text{u. } \Delta T$.
 $T = 10.9 \text{ gr. mm}^2$

 Fig. 37. $50.72^{\circ} \text{u. } \Delta T$

 Fig. 38. $50.42^{\circ} \text{u. } \Delta T$.
 $T = 11.25 \text{ gr. mm}^2$

 Fig. 39. $50.42^{\circ} \text{u. } \Delta T$.
 $T = 11.6 \text{ gr. mm}^2$

 Fig. 40. $50.42^{\circ} \text{u. } \Delta T$

On Three New and Remarkable Species of Echiuroids

(*Bonellia miyajimai*, *Thalassema tenuioides*
and *T. elegans*).

By

Iwaji Ikeda, *Rigakushi*.

With 4 plates.

While engaged in a study of the Gephyrean worms of Japan, I have devoted special care in examining the organization of three forms which seemed to me to be very remarkable in many respects, *viz.*, of *Bonellia miyajimai*, *Thalassema tenuioides* and *T. elegans*. All the three species, considered to be new, have already been described by me in short in a paper entitled "The Gephyrea of Japan."¹⁾ I now propose in the present article to describe them somewhat in detail, for which act I believe no apology is needed in view of the many points of peculiarities presented by them in their organization. Indeed some of their structural points appear to me to be of very great significance both from the systematic and the phylogenetic standpoint. The two species referred to *Thalassema* probably deserve to be made into a new and distinct genus: but for the present they may remain under the same generic designation used by me before.

¹⁾ This Journal, Vol. XX., Art. 4, 1904.

In this place I beg again to express my most sincere thanks to Professor MITSUKURI and Professor IJIMA, to whom both I owe much in completing this as well as my former paper on Gephyreans. My thanks are also due to my friend, Mr. MIYAJIMA, to whom I am indebted for the gift of the unique specimen on which I had based *Thalassema miyajimai*. Further I owe a debt of gratitude to Messrs. YATSU and TSUCHIDA for much valuable advice and assistance rendered me at Misaki.

1. *Bonellia miyajimai* I. IKEDA.

Figs. 1, 2, Pl. I. ; figs. 5-17, Pl. II.

1904. *B. miyajimai*, I. IKEDA, Jour. Sci. Coll., Vol. XX., Art. 4, p. 73.

The single (female) specimen as yet known of this species was obtained by Mr. MIYAJIMA in 1900 while on a collecting tour in the island of Okinawa, Loochoo Islands. It was found in a hollow in the coral rock along the shore in Tomari, a village two miles distant from the port of Naha.

On dissecting the female specimen I was fortunate enough to discover in the body-cavity a remarkable worm which I consider to be the parasitic male of the species.

The Female.

A colored drawing, in double natural size, of the female in the living state was made on the spot by the collector. It is now reproduced in fig. 1, Pl. I., of this paper.

External Characters.—The body proper is relatively short and thick ; it is ovoid in shape, being conically rounded posteriorly.

In the preserved state, it measures about 20 mm. in length and 10 mm. in maximum breadth. The proboscis is long and slender, being in the fully extended state nearly six times as long as the body proper. Anteriorly it splits as usual into two long branches; ventrally it is somewhat deeply grooved for the entire length.

The ground-color of the worm is a grayish brown; over it are scattered numberless small specks of a blackish brown color. These pigment specks are especially dense over the basis and the dorsal surface of the proboscis. The skin-papillæ are relatively small and sparse, except in the anterior and posterior parts of the body where they are slightly larger and crowded than in other regions.

One of the most peculiar features of the species is offered by the ventral hooks. Instead of being present in a single pair as in all other known *Bonellia*, they are very numerous, there being no less than twenty-nine in all (fig. 6, Pl. II.). Moreover, they are so small in size that they might easily be overlooked by the naked eye. They are of an elongate conical shape, gently bent like a horn, and measure commonly 0.5–1.5 mm. in length. Their color is a pale yellow. They are found irregularly scattered in a small area directly behind the oral aperture. Examined from the inside of the body-wall, the bases of the hooks are seen to be deeply implanted in two cushion-like muscular pads, symmetrically situated one on each side of, and in direct contact with, the ventral nerve-cord (fig. 5, Pl. II.). In the pads the inflated bulbs of the hooks appear as double-contoured circles (*h.b.*). Several branching muscles (*r.m.*) radiate from the pad periphery, soon to attach themselves to the body-wall.

Internal Characters.—The general internal anatomy of the female seems to agree nearly with that of *Bonellia viridis*, except in a few, not unimportant points.

The alimentary canal, throughout its convoluted course, is kept in position by numerous delicate muscle-threads originating from the body-wall.

The posterior end of the œsophagus is embraced by the heart, a broad vascular sinus of a triangular shape with the apex directed forwards. From the basal angles of the heart, there arise two moderately long vessels (commissures), which eventually join the ventral vessel running over the nerve-cord. That junction takes place somewhat behind the external aperture of the oviduct.

The oviduct (segmental organ) is single and unpaired, that of the right side being absent. The portion of the organ adjoining the external aperture is for a short distance thin and duct-like, the wall of the part being highly muscular; the rest of the organ is thin-walled, swollen and sac-like, extending behind nearly to the anterior border of the middle third of the body proper. The internal opening into the body-cavity is represented by a small, but very distinct, ciliated funnel, which is borne on the anterior end of the swollen oviduct, closely behind the point of its passage into the duct-like portion. The sac-like oviduct is found to be filled with eggs and presents a pale yellowish color. The ovary is represented by a long cellular band developed along the dorsal median line of the ventral blood-vessel.

The anal glands are relatively short, but bulky on account of the repeated branching of the main canal. The ultimate branchlets are beset with numerous ciliated funnels, each of which appears to be borne on a short thick stalk (fig. 7, Pl. II.). The free end of the main canal is fixed to the body-wall by a fine muscle-thread.

The Male.

As before mentioned, a male worm (fig. 2, Pl. I.) was discovered in the body-cavity of the female. It is to be presumed that the male had wandered into that organ through the genital passage, which in other species of the genus is known to be the seat of the parasitic male. I am strongly inclined to think that in the present species it is normal for the male to get into the body-cavity of the female and there to reach the state of maturity.

The male in question (fig. 2, Pl. I.) may be said, comparatively speaking, to be of very large dimensions. It is probably the largest ever recorded from among the Bonellian species. While in all the cases hitherto described the males rarely exceeded 2 mm. in length, that obtained by me in the present case is 28.5 mm. long and 2 mm. broad in the broadest part. The elongate body is cylindrical but tapers towards both ends. In the preserved state, it is bent into a shape resembling the Greek letter σ (fig. 2).

The unusually large size of the male worm seemed to greatly facilitate the study of its structure, and I have endeavored to take best advantage of that fact, with the hope of being able to contribute towards settling at least some points of dispute concerning the organization of Bonellian males. I think I have succeeded in bringing out several noteworthy points, partly apparently peculiar to the species and partly modifications or emphatically developed phases of corresponding characters in other species.

The skin presents a light yellowish color and a smooth appearance. It was however ascertained by observation under

the microscope that the epidermal surface is uniformly covered all over with closely set cilia. No ventral hook is present. The body-cavity, which extends through nearly the entire length of the body, is laterally compressed in relation to the considerable thickening of body-wall on the sides. In the anterior part of the body-cavity there are present four large funnels belonging to the vas deferens. The alimentary canal is not a continuous tube fixed at both ends to the body-wall, but is represented by a number of small isolated vesicles.

With these general remarks I will proceed to put down the results of my microscopic studies on the male.

The Body-wall.—This is of a very considerable thickness and is composed of five distinct layers, *viz.*, the epidermis, the dermal musculature, the trabecular layer, the subperitoneal musculature and the peritoneum.

The *epidermis* (*ep.*, figs. 8, 10, 11, 13) consists of very tall and narrow cells arranged side by side in a layer. The nucleus, rod-like in shape, is situated near the base of the cells. In fig. 8, which shows a part of a paratangential section through the body-wall, there is seen externally to all the structures the epidermis, which, being obliquely cut, presents a crowd of strongly stained nuclei in the basal parts. The cilia on the epidermal surface are developed, as already indicated, uniformly all over the body.

The *dermal musculature*, directly underlying the epidermis, consists of an external system of transverse and an internal system of longitudinal muscle fibers. The two systems are in direct contact with each other. Both are so very thin and the fibers composing them so fine that, in sections passing vertically through

them, it is with great difficulty that their presence can be ascertained. Very much easier is it to observe them on sections cutting them in an oblique direction, as, f. i., on a paratangential section such as shown in fig. 8 (*c.m.*, *l.m.*). Seen on such sections the continuity of both systems as layers is interrupted by the presence of a number of variously sized oblong spaces (*l.s.*, fig. 8) that interpose between the fibers. The spaces are elongate in the direction of the course of the fibers constituting the layer. A series of nuclei arranged in a line marks the boundary of the spaces, presenting an appearance as if the latter were provided with an endothelial lining. As a matter of fact, however, I believe the said nuclei belong to the connective-tissue and were apparently brought into the above arrangement by the pressure, as it were, of the spaces in question. These spaces themselves are evidently nothing else than direct continuations of the lacunæ of the trabecular layer.

The *trabecular layer* (*t.l.*, figs. 9-11, 13) forms a voluminous part in the entire thickness of the body-wall. Especially thick is it on the sides where the body-wall is thickest. It may be said that the layer consists of irregularly branching and anastomosing trabeculæ and of a system of irregular lacunar spaces that surround the trabeculæ. These seem to be essentially composed of fine, reticular and loosely bundled fibers—connective-tissue fibers—amongst which at certain intervals are seen the nuclei of the tissue. The trabeculæ contain, besides, a certain number of other fibers which, from their appearance, may be called muscular (*m.f.*, fig. 9). The lacunar spaces in the layer contain a lymph-like fluid that bathes the trabeculæ on all sides. The fluid can be deeply stained with hæmatoxylin. It is probably of a nutritious nature.

The above trabecular layer corresponds, in position at least, to the parenchymatous tissue of the authors on Bonellian males. That tissue has been generally considered to consist of an aggregation of stellate cells, a view which I am quite at loss to reconcile with what I have seen and described above. Some writers—amongst them VEJDovsky ('78) for one—have stated that blood-corpuscles and spermatozoa occur in the tissue-spaces of the parenchyma and that they both are generated from that tissue. Now, in the male of *Bonellia miyajimai* I can say with certainty that free cells never occur in the layer and that the male sexual cells originate, as will be shown further on, from a source apparently quite independent of the tissue in question.

The fourth layer of the body-wall is offered by the *subperitoneal musculature*, consisting of fine muscular fibers that run in oblique directions just outside of, and in direct contact with, the peritoneum. The layer is in general exceedingly thin and not always easily distinguishable. Only along the ventral median line of the body-cavity, it presents a not inconsiderable thickness. In this position, it can be plainly made out that there exist in the layer two intersecting systems of obliquely running muscular fibers (*o.m.*, fig. 9, Pl. II.). In each system the fibers are arranged in a single layer, nearly parallel with one another and in short but moderately uniform distances. Their course strikes an angle of approximately 40° in relation to the longitudinal body-axis.

It has been stated by some investigators of *Bonellia* that a peritoneal layer does not exist in the male. Contrary to this statement, I find the inner surface of the body-wall lined with a thin epithelium which might without impropriety be called the peritoneum (*pr.*, figs. 11 and 12). As seen in sections, it consists

of very flat cells arranged in a single row. It is uniformly developed throughout, except for a certain extent in the posterior parts of the body-cavity, along the ventral median line just above the nerve-cord, *i.e.*, in the region where the male sexual organ develops from the peritoneal layer.

The Ventral Nerve-cord.—This is an unpaired, medianly situated string of a considerable thickness, running in the ventral body-wall for nearly, but not quite, the entire length of the body (*v.n.*, figs. 9–13 and fig. 16, Pl. II.). In the greater part of its course, the cord heaves up from below the inner surface of the body-wall, thus bringing about a peritoneum-covered, broad, longitudinal ridge projecting into the body-cavity (fig. 16). Only in the anterior fourth of the body-length, this ridge formation does not take place; there the presence of the nerve-cord does not apparently directly affect the thickness of the body-wall (figs. 11–13). Anteriorly the cord terminates with two swellings situated side by side and which are separated from each other by an intervening lamina of the connective-tissue (fig. 10). They lie in about the same level with the anterior end of the body-cavity. Thus the nerve-cord does not reach up to the anterior-most end of the body; nor does it form any sort of a nerve-ring, which in males of other *Bonellia* species is known to exist around the sperm-duct. The bifid anterior termination may possibly be regarded as representing the remnant of a degenerated nerve-ring.

The Alimentary Canal.—Whereas in most Bonellian males hitherto known, the alimentary canal was found to be degenerated to the extent that it lacked both the mouth and the anal opening,

the male worm of the present species seems to have fallen into a state in which the degeneration of the same organ has gone a step further. This is manifested in the fact that the digestive tract does not exist as a canal but is evidently represented by a large number of separate vesicular sacs, floating freely in the fluid of the body-cavity. In my opinion, the sacs have arisen in that the alimentary tube has undergone division into pieces, which, by closure of the wall at ends, have each assumed a vesicular form.

My attention was first called to the vesicles as the male specimen was laid into oil preparatory to imbedding. Under the microscope they appeared as smooth-surfaced, regularly spherical bodies, varying in diameter from 0.2 mm. to 0.3 mm. They were found scattered in the whole extent of the body-cavity, apparently without any definiteness as to the manner of their occurrence.

Sections showed that the bodies in question are hollow spheres, closed on all sides and bounded by a thin continuous wall consisting of two epithelial layers (fig. 17, Pl. II.). The outer layer (*pr.*) is made up of excessively flattened cells arranged in a single row and looks quite like the peritoneal epithelium. In fact I believe it is nothing else than the peritoneal covering of the intestinal wall. The inner layer (*ept.*) is much thicker and is composed of approximately cubical or cylindrical cells, arranged likewise in a single row. The inner free ends of the cells are generally seen to be produced into a few pseudopodia-like processes of varying length. Frequently the processes send out branches. They may moreover anastomose with those from an adjacent cell. The body of the cells contain a number of large and small vacuoles, which often press aside the nucleus of the cell. The central cavity of the vesicular bodies in question contains no substance that can be revealed by staining.

It is out of question that the above vesicular bodies are results of mechanical injuries or of some sort of artificial treatment. Their wall never and nowhere shows an interruption or a histological disturbance which might be taken for an indication of recent severance by force. Since, now, there exists in the male specimen no trace of an alimentary canal, one is naturally led to the conclusion that this had broken up into the numerous vesicles above described, presumably by repeated constricting processes at an early period in the male's life.

An identical fate seems to befall upon the alimentary canal of the male of another species called by me *Bonellia misakiensis* (Jour. Sci. Coll., Vol. XX., Art. 4, p. 76). There I have found, instead of a continuous alimentary canal, about ten separate sacs of different lengths and sizes. These were scattered in the body-cavity, apparently standing in no definite relation to one another.

The vas deferens.—This presents some very remarkable peculiarities. In *Bonellia viridis*, *B. minor*, etc., according to SELENKA, GREEFF, RIETSCH, VEJDOVSKY and some other authors, the vas deferens is a long unpaired canal opening near the anterior body-end. It runs free in the body-cavity and should sometimes extend far backwards even into the posterior one-fourth of the body, finally ending with a single, large, ciliated funnel. The above holds good also for the male of *B. misakiensis*, which I studied. In *B. miyajimai*, however, the vas deferens is very short, scarcely longer than one-eighth of the body-length and posteriorly splits up into four branches, which arise in succession one behind another and each of which terminates with a long-stalked, large funnel. Externally the vas deferens opens by a minute aperture situated somewhat ventrally from the anterior

body-end. Further, the vas deferens does not run free in the body-cavity as it does in other Bonellian males, but stands throughout its entire length in connection with the ventral body-wall, only the four long funnel-stalks projecting free into the body-cavity. As determined from serial cross-sections, the vas deferens in the anteriormost parts is imbedded quite in the body-wall, running between the nerve-cord and the body-cavity (*v.d.*, fig. 12). The wall is internally lined by an endothelium and externally invested by a dense layer of reticular connective-tissue fibers; the lumen is filled up with spermatozoa, which fact greatly facilitates the tracing of the course of the duct. Posteriorly, the latter gradually recedes from the nerve-cord and comes to pursue its course in a longitudinal ridge that raises itself from the body-wall along the coelomic floor (*v.d.* in fig. 11). In the ridge just referred to, the vas deferens sends forth dorsally three branch canals in short succession; its posterior elongation after giving off the third branch may be called the fourth; so that it may be said that there exist in all four branch canals into which the vas deferens divides up posteriorly. Of the three canals cut across and indicated by the letters *v.d.* in fig. 12, the two upper ones are sections of the first and the second branch respectively, while the lowest is that of the posterior continuation of the main vas deferens before giving out the third branch. Fig. 13 represents a more posterior cross-section of the worm; in it we see the first and second branches (I. and II.) as free tubes—in the section both cut obliquely crosswise—in the body-cavity; the third and fourth branches (III. and IV.) pursue their course still within the narrow ridge of the body-wall just above the ventral nerve-cord. A short distance still more posteriorly, all the four branches are met with as free tubes as

shown in fig. 14. The tubes finally terminate each with a large ciliated funnel and may be called the funnel-stalk of unusual length. Their wall shows the same histological structure as the vas deferens of other Bonellian males, being made up of three layers; *viz.*, 1) the peritoneal epithelium (fig. 14, *pr.*), 2) the thin connective-tissue layer (*ct.t.*) and 3) the endothelial layer of the lumen (*ent.*). Both the peritoneal and endothelial layers consist of flat cells, except at the outflaring distal end of the funnel where the covering epithelium consists of cylindrical cells thickly ciliated on the exposed surface. The transitions of the flat peritoneum into this ciliated thickened epithelium takes place abruptly. In fig. 15 is shown a cross-section through a funnel right close to the internal opening. In it the non-ciliated thickened epithelium of the lumen is seen at two opposite places to pass directly into the outer ciliated epithelium and at other places to be separated from the latter by the connective-tissue, owing to the uneven configuration of the funnel mouth that had probably been brought about by the action of the fixing reagent.

Male Sexual Cells.—Small masses of spermatozoa are found floating in abundance in the cœlomic fluid. Each mass, spherical or ovoid in shape, consists of a central, comparative large spermatophore bearing numerous spermatozoa in the periphery. The former can scarcely be stained and is commonly vacuolated (fig. 14, *s.m.*).

As to the origin of the sperm-masses, two irreconcilable opinions had been advanced by previous authors. According to one view, they are formed in the parenchyma of the body-wall, *i.e.*, in a tissue which corresponds, as far at least as the position goes, to what I have called the trabecular layer in the male of

the present species. The other view maintains their production from the peritoneum at indefinite places. Now, in the male of the present species the question admits of a very clear solution. Here the testis may be said to be definitely developed, apparently from the peritoneum, as a longitudinal series of small cellular masses, projecting into the body-cavity above and along the ventral nerve-cord and borne on a narrow mesentery-like band. The testis in its entire length extends through the posterior three-eighths of the body. Fig. 16 represents, highly magnified, a portion of a transverse section through about the middle of the posterior half of the body. In it is seen the ventral nerve-cord (*v.n.*) in cross-section and surrounded by the reticular connective-tissue, which in its turn is delimited against the body-cavity by the thin peritoneum (*pr.*). In the middle above the nerve-cord is seen the testis in cross-section: supported on the mesentery-like band is one of a series of small spherical or ovoid bodies which I take to be the sperm-cell masses in an early state of development. Each such body consists of a protoplasmic ground-substance, containing in the periphery numerous, small and round nuclei which are probably to be seen in the light of spermatocyte nuclei. The central part of the body usually shows a roundish or oval, very faintly stained space, containing a single, likewise faintly stained nucleus and often one or more vacuoles in addition. I take no heed in identifying the substance of the central space with the spermatophoric mass of the detached and floating sperm-mass. Moreover, it seems to correspond to the central cell of a young egg-follicle in the female. As is the case with the latter, the central nucleated mass appears to undergo degeneration at a later stage; anyway, the single nucleus is no longer visible after detachment of the sperm-masses, the spermatophore then contain-

ing several large and small vacuoles only. By a careful observation of serial sections I have come to the conclusion that the several young sperm-masses are attached to the mesentery-like band for the most part in a single row, which, however, is not quite continuous, but is interrupted at intervals by gaps, presumably left behind by the falling off of the riper masses into the body-cavity. I am thus led to endorse SPENGEL'S ('79) view, so far as it goes, that the floating sperm-masses originate from the innermost layer of the body-wall, *i.e.*, from the peritoneum. However, in the male studied by me, they certainly do not arise from all over the latter, contrary to the opinion maintained by some investigator. The formative region is strictly confined to a narrow streak in the peritoneum, along the median line of the ventral body-wall. Thus, it is interesting to note, the testis presents a far reaching degree of identity with the ovary of the female, not only in origin and position but also to a certain extent even in structure.

The Cœlomic Corpuscles.—Besides the above described sperm-masses, the cœlomic fluid contains an abundance of free cells or cœlomic corpuscles (figs. 14 and 16, *b.c.*). Spherical or ovoid in general shape, the finely granular cytoplasm shows a nucleus which is full of deeply stained chromatin. They are especially numerous present in the posterior and anterior parts of the body-cavity, being at some places so closely packed together as to present an irregularly polygonal shape.

The principal features of *Bonellia miyajimai* may be summarized as follows:

The female. Body short, cylindrical, narrowed towards both

ends. Proboscis six times as long as the body; slender. Color grayish brown with minute blackish brown flecks. Ventral hooks numerous. Anal gland branched, bearing numerous stalked funnels.

The male. Found in body-cavity of female. Unusually large, being nearly 30 mm. long; without ventral hook. The greater part of the thickness of the body-wall presents a trabecular structure. Alimentary canal broken up into numerous vesicles. No nerve-ring is found. Testis in the same position and of essentially similar structure, as the ovary of female. Vas deferens divides posteriorly into four branches, each ending with a ciliated funnel.

2. *Thalassema tenioides* I. IKEDA.

Fig. 3, Pl. I.; figs. 18-22, Pl. II.; figs. 23-36, Pl. III.;
figs. 37-47, Pl. IV.

1904. *Th. tenioides*, I. IKEDA, Jour. Sci. Coll., Vol. XX., Art. 4, p. 63.

First an account of the circumstances that led to the discovery of the species may be given.

For a number of past years, the proboscis alone of the worm had been a rather well-known object to Japanese collectors, though its real nature had remained a standing puzzle to them. They had to do with a long, flat, bandlike object that often reached a length of one meter or more and had a breadth of 1-1½ cm. It was somewhat convex on one side and slightly concave on the other, the latter showing further a median longitudinal groove. Both sides presented a bluish-gray ground-color, variegated with

markings that consisted of narrow transverse stripes of a deep brown to brownish-black color. The stripes were either continuous from side to side or interrupted more or less in their course. Some of them were much narrower than others. They were very numerous and closely situated on the concave and furrowed side of the body, while on the other side they were present at wider intervals besides being represented always by irregularly broken or discontinuous streaks. The extreme ends of the body were either rounded off or notched in and strongly contracted, in the latter case appearing like the severed end of a preserved tapeworm. Wormlike as the object was, neither the head nor the tail end could be distinguished; nor was ever an opening that might pass for the mouth could be detected on it. In the living state, it exercised a slow wave-like movement that proceeded without a definite rule as to its direction.

The body in question has been taken from time to time in the sea near the Misaki Marine Laboratory. It has also been observed or obtained at several other localities; f. i., by Mr. NAMIYE in Tsushima (Strait of Corea) and in Tomo (Prov. Bingo, Inland Sea); by Mr. HATTA in Amakusa (Kiusiu); by Mr. YATSU in Haneda (Gulf of Tōkyō); by Professor OKA in Tateyama (entrance to the G. of Tōkyō); etc. It is evident that the creature is distributed over a wide stretch of the coasts of Japan.

At first sight one is irresistably led to assume that the object is a Nemertean. In fact it was surmised to be one—perhaps a highly degenerated form of the group—by several observers and more than one of them had gone into a study of its minute structure. At another time it had engaged the special attention of a student who had suspected in it an aberrant form of Turbellaria. But, after all, none of the observers could come to a

definite view as to the systematic position of the object supposed to be an entire animal. Its remarkable size and shape effectually held back idea of its being an Echiuroid proboscis. In 1900, Mr. YATSU took up the problematical object for a renewed study. I was kindly allowed to examine his sections and what at once called my attention was the close structural resemblance of the object with an Echiuroid proboscis. After making comparisons, Mr. YATSU and myself were both convinced of the fact that the object could be nothing else than an enormously long proboscis torn off from an unknown Echiuroid, the body proper of which has apparently never yet been obtained. At this I was given a free hand to track out the species and to continue the investigation. For this liberty and for placing all his material at my disposal, I beg here to express my thanks to Mr. YATSU.

During October and November 1901, I was at work in the Misaki Marine Laboratory, endeavoring to obtain the entire animal of the anticipated Echiuroid. With the kind assistance of Messrs. TSUCHIDA and AOKI of the Laboratory, I have finally had the satisfaction of securing in all six specimens of the animal, all living and with the body and proboscis in natural connection. They were all females.

As then ascertained by myself, the Echiuroid in question, called by me *Thalassema tanioides*, is by no means uncommon in the neighborhood of the Misaki Marine Laboratory. I have met with it most abundantly in the inlet Moroiso, right close to the Laboratory. It inhabits sandy or rather muddy but firm bottom, from between the tide-marks down to a depth of about seven fathoms. There the worm lives concealed in the burrow. Seen under water, the opening of the burrow appears as a small

pit of oval or roundish shape, and from it is protruded, in calm warm weather, the long proboscis of the worm, while the body proper remains entirely hidden. The proboscis may thus be exposed to a length of one meter or more; it is usually extended in a nearly straight line and rests flat on the bottom surface with the grooved (that is, the ventral) side facing upward. It then appears like a band of a dirty grayish color and might easily be mistaken for a dead leaf of *Zostera*. It makes a stretching movement, its free end moving from side to side, as if it were slowly creeping on the bottom. When disturbed by a touch with stick, or even when suddenly covered by shadow as it lies extended on the sun-lit bottom, the proboscis is rapidly and entirely withdrawn into the pit-like burrow.

For obtaining the worms, search was made for the protruded proboscis in such places as will be exposed above water during the low tide. The position was marked by planting bamboo sticks close to the burrow pit. By the time the place was sufficiently out of water, it was revisited and the digging out of the worm was done. In this way I have learned that the burrow sinks perpendicularly to a depth of 70–90 cm. into the moderately firm ground. It is tubular and cylindrical, measuring for the most part about 2 cm. in diameter; near the lower end it is considerably wider, reaching up to 4–5 cm. across. The wall surface of the tube is smooth and bears a rusty reddish color.

External Characters.

Having failed to obtain a male specimen for study, all my observations on the external and internal organization of the species are based on the female.

The species is a remarkably large form. In Pl. I., fig. 3 is shown in natural size the smallest specimen I have obtained. The body proper may measure 40 cm. in length and 2–3 cm. in greatest width. The proboscis in the fully extended state may be 150 cm. long and 1–1½ cm. broad. So that, a large individual when fully extended may reach 190 cm. in total length.

The general appearance of the proboscis has already been described. Here it remains to be mentioned that the basal portion of that organ, for a length of 5–8 cm. in front of the mouth, is quite free of the transverse stripes on both surfaces and presents a grayish to light-brownish yellow color, which deepens in tone towards the position of mouth. At the transition of the proboscis into the body proper, the former forms an incomplete funnel around the mouth. The free distal end of the flat proboscis is simply rounded.

While in life, the worm incessantly changes shape and dimensions by alternately contracting and stretching out, but the shape given in fig. 3 may be considered to represent its normal state of rest. In that condition the body is cylindrical and broadest near the hind end, which is itself conically pointed. Anteriorly it very gradually narrows towards the oral end.

The skin presents a brownish red tint over a pale yellow ground. It is thickly beset with small papillæ of a light ochraceous color and of various shape and size. They are largest and most crowded near both ends of the body, where most of them present a star-like and not a round outline. Except near the body ends, there are seen on the surface narrow longitudinal lines, in all five in number, running equidistant from one another. The lines are of a light yellowish color and are somewhat translucent; they can be best seen when the body is in a contracted state.

On account of their presence the muscular layers of the body-wall appears divided into five broad longitudinal zones.

A short distance (1–1.3 cm.) behind the mouth there exist a pair of moderately long ventral hooks. These are gently curved mediad and are of a bright yellow color.

Some Points of the Internal Structure.

Figs. 18 and 19 in Pl. II. and fig. 23 in Pl. III., all drawn from dissections of the worm, will serve to give a general idea of the arrangement of internal organs. For study of the microscopic structure were employed material which were fixed with either saturated corrosive sublimate solution or FLEMMING's strong solution. HEIDENHAIN's iron-hæmatoxylin or DELAFIELD's hæmatoxylin was used for nuclear stain, and several anilin pigments for plasma stain. In the following description, I will first take up the body proper, leaving the proboscis to be dealt with last.

The Body-wall.—In the living state of the worm, this is relatively thin. It grows somewhat thicker towards both ends of the body, where the surface is beset with largest papillæ. It may be said to be made up of five distinct layers, *viz.*, the cuticle, the epidermis, the cutis, the muscular layer and the peritoneum (fig. 26).

The *cuticle*, which forms the outermost covering, is moderately thick (figs. 27 and 28, *et.*). As was pointed out by JAMESON ('99) in *Thalassema neptuni*, it is composed of an outer deeply and an inner less deeply staining layer and of the innermost alveolar layer.

The *epidermis* is represented by a single-layered epithelium

composed of tall cylindrical cells (figs. 26-28, *ep.*). While it presents a smooth surface against the cuticle, the internal contour is irregular, owing to the fact that the inner ends of the component cells are produced into a few number of finely tapering and branching processes as had been observed by many previous investigators (fig. 27). The processes penetrate for a short distance into the cutis and anastomose with one another as well as with the connective-tissue fibers of the cutis. At places they are further seen to stand in connection with certain processes of sub-epidermal ganglion cells (*n.c.*), which again are directly traceable to comparatively thick nerves (*n.*) running in the cutis. In rare instances I have observed in the epidermis small compact groups of club-shaped epidermal cells, which were somewhat sunk into the cutis with their swollen inner end (*s.o.*). It looked very much like a sense-organ and I am greatly inclined to consider it to be one, although no hair-like appendage could be made out at the outer end of the cells.

Here and there among the ordinary epidermal cells are found those which look very much like a mucous cell (figs. 27 and 28, *gl.*). They are of a swollen appearance, due to the clear secretory contents which press the cytoplasm and nucleus against the cell base. As JAMESON has said, the glandular cells in question—for they are without doubt unicellular glands—show no external opening. Quite another kind of unicellular glands is numerous met with in the larger dermal papillæ (fig. 28, *g.gl.*). Here we have to do with elongate club-shaped cells of a large size, which lie for the greater part of their length imbedded in the cutis and which with their distal narrowed end pass between epidermal cells and finally open externally each with a pore through the cuticle. I distinguish two varieties of the glandular cells in

question. The one is much larger and more elongated than the other and exhibits finely granular contents which stain deeply with hæmatoxylin. The same glandular cells occur also on the dorsal side of the proboscis (fig. 45). They are apparently the same as the similarly situated unicellular glands, known to occur commonly in other Echiuroids. The second variety of the glands is characterized not only by being shorter but also by having an almost homogeneous plasma containing some coarse granules which are intensely stained by eosin or erythrosin. So far as I know, this kind of the glandular cells has never yet been described from other Echiuroids. The cutis (figs. 26-28, *etc.*), the mesenchymatous layer directly underlying the epidermis, is comparatively thick. It attains greatest thickness in dermal papillæ, of which it in fact forms the main internal mass. The tissue consists of a clear ground-substance which is traversed by numerous, irregularly branching fibers, as in a fibrous connective tissue. Most of the fibers take a course vertical to the body surface. Here and there the fibers are seen to emanate from the ends of slender spindle-shaped cells, of which they seem to be direct prolongations. The same connective-tissue cells and fibers occur also in deeper parts of the body-wall among the muscle fibers.

In the cutis and especially numerous in its superficial parts are met with some nerves and ganglion cells, of which mention was already made. Inclosed in the layer are further peculiar pigment bodies (*pg.*). They are of a spherical shape, and contain innumerable minute granules of a brownish color. They occur most abundantly in the deeper part of the cutis and in the non-papillated region. There is another sort of pigment-like bodies (*pg'.*) which are found most abundantly in the peripheral parts of the cutis. They are of various sizes, are quite homo-

geneous in structure and can be deeply stained with hæmatoxylin. The possibility is not excluded that the bodies here referred to are but coagulated masses produced from the lymph-like fluid that permeates the cutis tissue.

At places in the cutis, especially in close proximity to the epidermis, are found relatively large cells of a roundish shape, with finely granular cytoplasm strongly stainable with eosin (figs. 27 and 28, *w.c.*). They are devoid of plasmic processes and can therefore be easily distinguished from ganglion cells. Possibly they represent a sort of free wandering cells.

The strongly developed *muscular layer* is of the usual composition, consisting, as it does, of the longitudinal (fig. 26, *l.m.*), the circular (*c.m.*) and the oblique systems. The longitudinal system forms a continuous sheet. To special thickenings of that sheet are due the five, equidistant, pale-colored, longitudinal lines visible on the outside of the body-wall.

Here may be mentioned the well developed muscles that are attached to the bulbous bases of the paired hooks. One of them, the interbasal muscle (figs. 18 and 19, *i.m.*), stretches itself transversely between the hook bulbs; the rest are the radial muscles (*r.m.*) that radiate from each of the latter.

With regard to the peritoneal lining of the body-wall, I have found no points of special interest. The internal surface of the body-wall presents a deep brownish red color.

The Alimentary Canal.—This is exceedingly long and takes a convoluted course which is complex but definite (fig. 23). Throughout its length the canal is fixed to the body-wall by means of numerous muscular filaments and by some muscular mesenteries. It may be said to consist of five main parts, *viz.*,

the pharynx, the œsophagus, the crop, the midgut and the intestine. The names here employed to designate the different parts are in a measure provisional and may not be exactly identical with the parts called by the same names in other Echiuroids. I have found it not always an easy matter to draw homology between the different regions of the digestive tract in the present species and those in other Echiuroids.

The mouth leads into the *pharynx* which is a sac-like, relatively short, muscular tube (figs. 18, 19 and 23, *ph.*). In preserved specimens it is about 45 mm. long and 7–10 mm. wide. It is the widest and the thickest-walled part of the entire digestive canal. When filled with sand it may be distended into a large thin-walled sac. The outer surface of the wall is smooth ; under circumstances the circular folds of the inner surface may be seen on the outside through the semitransparent wall. For its entire length the pharynx is fixed to the body-wall by a pair of tolerably wide and thick suspensory membranes of muscular nature, the wing muscles or lateral mesenteries (fig. 23, *w.m.*). These arise right and left from along the lateral sides of the pharynx and insert themselves on the body-wall along two parallel lines, each running 7–10 mm. apart from, and on either side of, the ventral nerve-cord. The two mesenteries are asymmetrical in that the one on the left side terminates behind with a free edge which slants down ventro-posteriorly from the hind part of the pharynx, while the other on the right side is more prolonged and extends farther backwards in connection with the œsophagus, at the same time the line of its parietal insertion gradually approaching the ventral median line. The right lateral mesentery just referred to terminates posteriorly by becoming confluent with the suspensory membrane (*d.m.*) of the dorsal

vessel (*d.v.*), at a point a short distance in front of the junction of the posterior end of the œsophagus with the crop (*cr.*). I shall return to this suspensory membrane in relation with the dorsal vessel.

The *œsophagus* (fig. 23, *œs.*) is a narrow muscular-walled tube 2–4 mm. wide and which, when stretched out, may measure 200–300 mm. in total length. From the hind end of the pharynx it proceeds posteriorly down to about the middle of the body length; then it makes a sharp bend forwards, thus bringing about a narrow U-like loop. The ascending limb of the loop, on reaching a point a short way behind the posterior end of the suspensory membrane (*d.m.*) of the dorsal vessel, makes another sharp bend but this time backwards. Just at this point the œsophagus passes over into the third section of the alimentary canal, the crop (*cr.*). The first part of the œsophagus from the pharynx to the posterior end of the suspensory membrane of the dorsal vessel is, as before indicated, connected with the body-wall by the right lateral mesentery. The same part is further peculiar in that it is internally provided with a typhlosole-like structure projecting into the lumen along the midventral line (fig. 35, *ts.*). In addition to the above mentioned mesentery, the œsophagus is fixed in its entire length by a series of muscular strands which spring from the body-wall close to the ventral nerve-cord on the left side.

The *crop* (fig. 23, *cr.*) is, like the foregoing section, a narrow tube but is characterized by the internal surface being beset with villi-like papillæ. In the empty state it is 70–90 mm. long and 3–4 mm. wide. It takes a linear course and is furnished throughout its length with the ventral mesentery (*v.m.*) which is inserted on the ventral body-wall close to, and on the left of, the nerve-

cord. Of this mesentery the parts immediately adjoining the crop wall form a gland-like structure of a reddish brown color (fig. 37, *g.l.s.*).

The crop is followed by the *midgut* (fig. 23, *m.g.*). This is about three times as long as the former. The inner surface is put into closely set transverse wrinkles, instead of having papillæ. The tube bends forwards and backwards several times so as to form irregular W-like loops. It is not supplied with a mesenterial membrane but is fixed to the body-wall by a series of numerous muscle-threads, which on the whole are arranged in the manner of a mesentery. In all the specimens examined, the crop was found to be infested by an abundance of a Sporozoan parasite.

The boundary between the crop and the next following section, the intestine, is externally marked by the anterior end of the collateral intestine or the siphon (*c.i.*). The *intestine* proper is a comparatively wide (4–7 mm.), complexly winding tube of a great length. When straightened out, it may measure nearly $1\frac{1}{2}$ meter in length. The inner surface is thrown into small transverse folds, which can be seen from the exterior through the thin wall. Like the preceding part of the digestive tract, the intestine is held in position by a mesentery-like series of very numerous muscle-threads. It may be distinguished into two parts. The first part (*in.*), making up about two-thirds of the length of the entire intestine, is accompanied by the collateral intestine (*c.i.*); it takes an irregularly winding course down to nearly the posterior end of the body-cavity and then turns round forward, to pass over into the second part at a certain distance. The second part (*in'.*) all along exhibits the siphonal groove (*s.g.*), brought into view owing to the absence here of the overlying

collateral intestine and which runs down nearly as far backwards as the junction point of the anal glands. The part in question of the intestine lies ventral to the windings of the first part and takes at first an anteriorly directed course up to about the middle of the body; it then makes a sharp bend, thence to run backwards down to the anus at the posterior body-end. The terminal part of the intestine which may be called the rectum, is very short.

The alimentary canal in its entire length, excepting the pharynx and the "typhlosohle" bearing portion of the œso-phagus, is always filled with fæces which are in the shape of small rods.

Having given above the gross features of the alimentary canal, I will now pass over to its microscopic structure. In this respect the present species presents not a few points of peculiarity. For the sake of comparison, I have studied histologically the same organ-system of *Echiurus uncinatus*, a species which moreover was thoroughly described by SELENKA ('85) and ALICE EMBLETON ('00); and I have found that, while that species presents an essential agreement with other previously known Echiuroids in the anatomy as well as the histology of the digestive system, the present species shows no small degree of deviation in those respects, especially as regards the microscopic structure of the foregut and of the anterior portion of the intestine.

The wall of the pharynx consists of four layers, *viz.*, the mucous membrane, the muscular layer, the trabecular layer and the peritoneum. See Pl. III., fig. 32, which represents a part of a cross-section through the pharynx and the wing-like lateral mesenteries (*w.m.*).

The mucous membrane (fig. 32, *m.m.* and fig. 33) constitutes a moderately thick, much folded layer, which again is made up of the lining epithelium (*ept.*) and the subjacent connective-tissue layer (fig. 33, *c.t.l.*). The former is composed of tall and narrow cells containing nucleus in about the middle of their length. Their internal or free end is covered with a thick cuticle (*ct.*), while the opposite, much narrowed end seems to be directly continuous with a process of the connective-tissue cell. Hence, there exists no sharp demarkation of the epithelium against the underlying tissue. As was noted by JAMESON ('99) in *Thalassema neptuni*, the pharyngeal epithelium incloses numerous club-shaped, unicellular glands (*gl.*) with colorless homogeneous contents, in which is observable a deeply stainable, more or less reticular structure. The nucleus in these glandular cells lies always near the swollen inner end. The connective-tissue layer (*c.t.l.*) between the epithelium and the muscular layer, is of a considerable but varying width. It is composed mainly of fusiform or branched cells, which send out slender processes that give a fibrous appearance to the tissue. A quantity of variously sized, deeply stainable spherules are contained in the layer; they are in all appearance the same as those found in the cutis (fig. 26, *pg'*.).

The muscular layer of the pharyngeal wall consists of the inner circular and the outer longitudinal systems (fig. 32, *c.m.* and *l.m.*). The latter, according to both RIETSCH ('86) and JAMESON ('99), should be entirely wanting in *Thalassema neptuni*, while in *Echiurus uncinatus* and *E. pallasi* it is only weakly and inconspicuously developed. In the present species, that system is remarkably well developed, forming a layer nearly equal in thickness as that of the circular muscle system.

Externally to the muscular layers is what I have called the

the trabecular layer (fig. 32, *lt.*, and fig. 34), which is probably identical in nature with the layer I have described by the same name from the body-wall of the male of *Bonellia miyajimai* (p. 7). The layer in question of the pharyngeal wall consists of an irregular network of strands, inclosing roundish meshes of various sizes. See *fig.* 34, which represents under high magnification a small portion of the layer in section. The said strands are made up of a stainable ground-substance, in which are numerous connective-tissue fibers and a sparse number of cells, besides being traversed by some isolated muscle fibers (*m.f.*). The meshes form in reality a system of irregularly branching and freely anastomosing canals, the lacunar sinus (*l.s.*). The sinus contains numerous amoeboid cells (*w.c.*), laden with spherules which are of a yellowish brown color in the fresh state and which stain deeply with hæmatoxylin. The cells are of various sizes, the size apparently depending upon the quantity of the spherules contained in the cell-body.

The peritoneum investing the external surface of the pharyngeal wall requires no special description beyond mentioning the fact that it consists as usual of greatly flattened cells.

Of the several layers composing the pharyngeal wall, the connective-tissue layer of the mucous membrane and the trabecular layer were not known before from any *Thalassema*. In *Th. neptuni*, according to JAMESON ('99), both the inner lining epithelium and the peritoneum should directly overlies the middle layer consisting of circular muscle fibers alone. In *Echiurus uncinatus*, I have found that a connective-tissue layer is present beneath the inner lining epithelium, but no trace of a trabecular layer beneath the peritoneum.

The wall of the œsophagus is structurally nearly similar to

the pharyngeal wall, except in the more conspicuous development of the longitudinal muscle system and in the absence of the trabecular layer. The typhlosohle-like ridge (fig. 35, *ts.*) in the anterior part of œsophagus is superficially covered with an epithelium, in which cell outlines are indistinct but which exhibits nuclei arranged in a row (fig. 36, *ept.*). The epithelium contains a large number of small, yellowish brown spherules, either in a scattered manner or in irregular and indefinite groups. The spherules are probably the same as those contained in the wandering cells. The main internal mass of the ridge is a transparent chondroid substance, contained in which are a few cells and some peculiar fibers. The former (*c.t.c.*) are without doubt of mesenchymatous nature; they send forth into the ground-substance a number of long and slender, fiber-like processes. The latter are filaments of a considerable thickness; they are irregularly wavy and run in indefinite directions. Apparently they stand in no direct connection with any of the cells, and their appearance leads one to compare them with elastic fibers in the connective tissue of the higher animals. From its structure the typhlosole-like ridge can scarcely be assumed to be an organ of secretion or of absorption. More probably it is an apparatus which may aid in the mechanical crushing of the food mass taken in.

The villi-like papillæ, the presence of which characterize the inner surface of the crop, are of a very remarkable histological structure. They consist almost wholly of a syntitium, evidently formed by fusion of the epithelial cells (fig. 38, *ept.*). The internal surface shows no ciliation. As seen on cross-sections, there opens a large unicellular gland (*gl.*) nearly regularly in the depression between the bases of every two papillæ. In this

section of the alimentary tract as in all following sections, the longitudinal muscle layer (*l.m.*) lies internally to the circular (*c.m.*), the reverse of the order seen in the pharynx and the œsophagus. The former layer is in contact with the basal surface of the internal epithelium and is longitudinally folded. Where the folds recede from the unfolded circular muscle layer there exists a connective-tissue space of a considerable width. The peritoneal covering (*pr.*) of the crop is quite peculiar in that here, as nowhere else on the entire alimentary canal, it is composed of tall cylindrical or even club-shaped cells with coarsely granular contents.

In connection with the crop I may here deal with the structure of the ventral mesentery which joins it to the ventral body-wall. That mesentery (fig. 37, *v.m.*, and fig. 39) is of a considerable thickness; it incloses in the interlamellar connective-tissue layer sinus-like spaces in which are found some wandering cells (fig. 39, *w.c.*). These cells are quite indefinite in shape, being sometimes elongate, sometimes ovoid and at other times amœba-like. Most of them, but not all, contain in the cytoplasm a limited number of yellowish brown spherules, which are in all probability the same as those found in coelomic corpuscles and in the peritoneal cells to be directly described. As before mentioned, the ventral mesentery presents a glandular appearance in the parts adjoining the crop (fig. 37, *g.l.s.*). This is due to the facts that the surfaces of the mesentery are thrown into numerous small folds and that the peritoneal covering is thickened and is converted into a peculiar structure. Fig. 39 shows highly magnified a small portion of a cross-section through the mesenterial part in question, with two folds on its side. It will be seen that the peritoneum of this region is characterized firstly by the

fact that it is at most places more than one cell in thickness, and secondly by the relatively bulky component cells containing an abundance of variously sized spherules of a yellowish brown color. Those cells [*a* (*pr.*)], which sit with one end directly on the subjacent connective-tissue, are of an oblong or elongate shape and possess round nucleus with distinct chromatic bodies, while the others [*b* (*pr.*)] more superficially situated are shorter, being roundish or irregular in shape, and show clear looking nucleus with only a few and indistinct chromatic bodies. Some of the latter kind of the cells detach themselves from the peritoneal surface and fall into the cœlomic cavity. Evidences of this fact can be easily obtained by tracing on serial sections. The cells thus liberated can impossibly be distinguished from the corpuscles (*b.c.*) found floating in the cœlomic fluid. In fact I take no heed in regarding the region in question of the ventral mesentery to be the formative source of all the cœlomic corpuscles.

Passing on to the midgut, I find that the small transverse folds on the internal surface are formations of the lining epithelium alone (fig. 40, *ept.*). They are made up of spindle-shaped or pyramidal epithelial cells arranged in several layers with their long axis directed nearly vertical to the epithelial base; whereas at the bottom of the narrow depressions between the folds, the epithelium consists of comparatively short cylindrical cells in a single layer. Near the free internal surface of the folds are some small unicellular glands (*gl.*) of a flask-like shape, opening by narrow duct into the gut lumen. Close to the base of the epithelium is the layer of longitudinal muscle fibers (*l.m.*). That of circular muscle fibers (*c.m.*) lies more externally and close under the peritoneum (*pr.*). This is composed of cells which

are not quite flat nor cylindrical but present a somewhat swollen appearance.

To judge from the arrangement of the musculature, the crop and the midgut, taken together, probably correspond to the anterior portion of RIETSCH's "intestine intermediaire" in *Th. neptuni* and to JAMESON's "crop" or the anterior portion of his "intestine" in the same species. However, there exists in this respect a notable discrepancy in the fact that neither the crop nor the midgut in the present species is provided with the siphonal groove, which does not extend, as it does in other *Thalassema* species, farther anteriorly than the anterior end of the collateral intestine.

With regard to the wall of the part called by me the intestine, I have found the finer structure to be essentially the same as is known from the intestine of *Thalassema neptuni*, *Echiurus pallasii*, *E. uncinatus* and several *Bonellia* species. Only the internal epithelium of the collateral intestine presents a condition which seems to deserve a brief description. Fig. 41 represents a portion of a cross-section through that organ, seen under a high power of magnification. The internal epithelium (*ept.*) forms a few number of longitudinal ridges that project into the lumen and greatly narrow it. Each of these ridges may be said to consist entirely of a continuous mass of protoplasm, apparently the result of fusion undergone by the epithelial cells. The nuclei are visible only near the free surface, arranged in a single irregular row. Interspersed among the nuclei are a number of vacuole-like spaces. All the internal parts of the ridges consist of a densely and coarsely granular mass containing numerous pigment spheres of various sizes (*pg.g.*).

The *anal glands* (fig. 23, *a.g.*), present in a pair, open into the very short rectum. They are brown tubes of 6-7 cm. length, fixed at the extreme tip to the body-wall by a long and slender muscular thread. The main canal of the organ is thickly beset all over with tubules, which are either simple or are divided into 2-5 branches (fig. 25). Distally the tubules or their branches pass over each into a relatively large and long funnel-tube of a deep brown color.

The Segmental Organs.—I have devoted special attention to the segmental organs which offer the most striking characteristic of the species. They are present in a very large number (figs. 18 and 23, *seg.*). They were never less than 200 in total number, and in certain individuals I have estimated this to be nearly 400. Moreover, unlike all other known Echiuroids, there is no indication of their segmental arrangement, nor of their strictly paired disposition. On the contrary, they occur densely and irregularly crowded together in two longitudinal zones, one on each side of the ventral nerve-cord, beginning in front just behind the ventral hooks and extending posteriorly to a length of 10-18 cm. In the anterior parts of each zone, some four or five segmental organs stand abreast; in the middle parts, three (see fig. 18, *); more posteriorly, two (fig. 29); and finally in the posteriormost parts, they occur in a single row.

Each single segmental organ is a thin-walled, elongate, bottle-shaped tube, measuring 10-12 mm. in length in the fresh state (see fig. 24). Internally it ends with a relatively large and apically situated ciliated funnel (*fn.*). To my knowledge, such an apical position of the funnel on segmental organs has not been known before from other Echiuroids. All the specimens

examined by me being sexually ripe females (obtained in November and December), I have found the swollen part of the segmental organ filled with spherical ova of a light yellow color.

Studies of the segmental organ on sections (figs. 29–31) did not bring to light much structural peculiarities. In fig. 29 is given a sketch of a small portion of the body-wall in cross-section, showing the position of the organs on either side of the ventral nerve-cord (*v.n.*) and the manner of their opening externally on the ventral surface (*ex.o.*). The part of the out-leading duct directly adjoining the external opening is characterized by being lined with a thick epithelium extremely rich in unicellular glands (fig. 30, *gl.*). These are of an elongate oval shape, each opening on the external end with a comparatively large and distinct pore. Their contents show a coarse reticular structure, deeply stainable with hæmatoxylin; the nucleus is found always near the inner cell end. The true epithelial cells lie so narrowly compressed between the glandular cells that their limits can not be made out (*ep.*). However, their nuclei can be easily distinguished by their oblong shape, while those of the underlying mesenchyme cells are round and somewhat larger. The main tubular part of the organ has thin wall, the structure of which is shown in fig. 31 in longitudinal section. The internal epithelium (*ept.*), as also the external peritoneal covering (*pr.*), is composed of very flat cells in a layer. Almost in contact with the internal epithelium is a layer of longitudinal muscle fibers (*l.m.*). Between this and the peritoneum is a connective-tissue layer, in which run a number of muscle fibers in indefinite directions (*o.m.*).

With regard to the form and structure of the ciliated funnels (fig. 24, *fn.*), no point of special interest has come into my notice.

The Circulatory System.—This is essentially of the same arrangement as in other known Echiuroids, except in a few points. One remarkable feature of it consists in the unusual length of the vessel (figs. 18, 19 and 23, *d.v.*), a fact which stands in relation with the posterior situation of the so-called heart. This describes as usual a curve embracing the alimentary canal,—in the present species, at the posterior end of the midgut. As before indicated, a large part of the dorsal vessel in front of the crop is fixed to the body-wall by a mesentery-like suspensory membrane (fig. 23, *d.m.*). Such a membrane is unknown in other Echiuroids, the dorsal vessel running free in the body-cavity throughout its entire course. The parietal insertion of the said suspensory membrane is dorsal in the anteriormost part. Posteriorly its course gradually changes into lateral on the right side of the worm and finally into ventral. Soon after this, the membrane becomes confluent with the right lateral mesentery before described. More posteriorly from this point, the single membrane formed by the confluence connects the dorsal vessel to the dorsal surface of the oesophagus and no longer to the body-wall. This condition obtains for a length of 10–20 mm. in about the region marked with * in fig. 23. After that, the posterior continuation of the membrane separates from both the dorsal vessel and the oesophagus, and runs for a short distance with free edges until it becomes continuous with the ventral mesentery (*v.m.*), which joins the crop to the ventral body-wall on the left of the nerve-cord. From the point the suspensory membrane leaves off the dorsal vessel, this runs of course free in the body-cavity down to the heart, except at a single point 10–12 cm. from the mouth. The point is marked with + in fig. 23. There arises from the vessel a short and slender muscle thread, which

inserts itself on the ventral body-wall on the right of the nerve-cord.

The heart and the ventral vessel are joined by a relatively short (3-4 cm.) commissure or neuro-intestinal vessel (fig. 23, *n.i.*). This arises from the heart with two roots, so that it presents the shape of an inverted Y. The ventral vessel (figs. 18, 20, 23 and 29, *v.v.*) runs throughout its length just above and along the ventral nerve-cord. Like this it bifurcates immediately behind the mouth. The two vessels thus formed proceed into the proboscis and constitute the lateral vessels of that organ (fig. 20, *l.v.*). In three specimens out of the six dissected, I have ascertained the presence, on the ventral vessel, of a peculiar slender branch which probably corresponds to the ring-vessel described by SPENGLER ('80) from *Echiurus pallasii*. The vessel in question (figs. 19 and 20, *r.v.*) branches off from the ventral vessel at a point about 1 cm. behind the ventral hooks and runs forwards over and beyond the interbasal muscle of the hooks. Arrived at a close proximity to the bifurcation point of the ventral vessel (see fig. 20), the vessel under treatment (*r.m.*) splits into three short branches. Of these the two lateral branches soon join the roots of the lateral vessels (*l.v.*) of the same side, while the single median branch communicates with the anterior end of the ventral vessel at the bifurcation point.

As regards the finer structure of the heart and the vessels, I have scarcely anything to add to what is already known from other Echiuroids. Only let it be mentioned that the ventral vessel of the ventral vessel has an internal lining epithelium consisting of tall club-shaped cells with the swollen rounded end projecting more or less free into the lumen. See *ept.* in fig. 42, which shows a longitudinal section of the wall of the vessel in question.

The Ovary.—As already stated, all the six specimens examined by me were females. In all the cases, the ovary was developed as a long narrow band, lying over the posterior parts of the ventral vessel for an extent of about one-sixth of its total length. Structurally the organ offers no new points worth specially mentioning.

On the same ground I may altogether dispense with giving an account of the nervous-system.

Floating Bodies in the Cœlom.—Besides the cœlomic corpuscles already referred to (fig. 39, *b.c.*), the cœlomic fluid further contains two kinds of peculiar floating bodies that require to be described. One of them shall here be called the corpuscular bodies; the other is the so-called "Töpfchen."

The corpuscular bodies are of very various sizes. The larger ones measure 1–2 mm. across and are easily seen with the naked eye. Spherical in shape, they are of a dark reddish or of a dark violet color in the fresh state. Examined under the microscope, they are found to be hollow blastula-like spheres, the wall of which consists of an epithelium-like aggregation of remarkable looking cells disposed in a layer. Seen on the surface, the cells present an irregularly lobed appearance, tightly clasping one another with the lobes (fig. 21 *a*). A distinct boundary membrane exists between them. The finely granular cytoplasm incloses a number of refractive granules or spherules of a deep brownish-violet color. The nucleus is spherical, shows a relatively thick nuclear membrane and is but little affected by ordinary nuclear stains.

The physiology of the above described bodies remains completely in the dark. As to their origin, a clue might be found

by a study of the smaller ones which are apparently in the process of development. With the decrease in size of the bodies, I find that the component cells grow continually less in number, the lobe-like processes of these less pronounced and the internal cavity less spacious. So by a gradational series of transitional forms, the blastula-like bodies are led over to a simple group of a few number of cells (fig. 21 *b*) which are simply oblong or subspherical in shape and cohere together like blastomeres in a segmenting ovum. Such a small group may be formed of only four or three or even two cells. Each cell then compares well in appearance with the unicellular blood-corpusele (fig. 39, *b.c.*) found likewise free in the body-cavity, though generally slightly larger in size. In fact, the identity of the cells referred to seems to scarcely admit of a doubt. It may then be thought of that the polycellular body arises by repeated division of the unicellular corpusele. And yet, notwithstanding careful researches, I have never been able to detect a sign of cell division in the cells, irrespective of these being isolated or combined. It seems to me not improbable that in view of their extreme poverty in chromatic substance, the nuclei of the cells in question are in an inactive state as regards the dividing power. If now the polycellular bodies are really formed of the unicellular corpuseles, I should think the mode of formation is not by repeated cell-multiplication but by aggregation of the latter in as many number as the body is seen to consist of.

The "Töpfchen," commonly found in the body-cavity of Gephyrean worms, is in the present species a small globular body provided at one part with a relatively large and ciliated funnel-like opening (fig. 22, *fn.*). The funnel wall is covered with a

tall ciliated epithelium. For the rest the external surface is covered with a flat non-ciliated epithelium. The interior of the body is filled with a mass of irregularly shaped cells, which mass inclose a number of brownish pigmented spheres. The internal termination of the funnel could not be exactly determined.

The above peculiar body is a thing which is by no means satisfactorily known. Most of the earlier and some recent writers have regarded it to be a parasitic organism, while some others, f. i., METALNIKOFF ('00), have considered it to be a liberated part of the worm-body. Although unable to offer decisive evidence, I am certainly inclined to accept the latter view.

The Proboscis.—The long tape-like proboscis in transverse section presents a crescent-like shape, the concave side of which is the ventral.

The epidermis (*figs. 43-45, ep.*) is composed of a layer of cylindrical cells with round nucleus situated nearly in the middle and containing a distinct nucleolus beside numerous chromatic granules. On the external surface the epidermis shows a very thin cuticular layer and bears fine cilia on the ventral side of the proboscis but not on the dorsal. Internally the epidermis sits on a fine but sharp basal membrane (*figs. 44, li.m.*), the cells being quite without the basal processes that we have seen in the case of epidermal cells of the body proper. The epidermis is thickest and the ciliation most conspicuous along the margin of the ventral surface (see *fig. 43*). Peculiar to the epidermis of the dorsal side is not only the absence of ciliation but also the fact that there open through it numerous unicellular glands (*fig. 45, g.gl.*) similar to those found in certain parts of the body

proper. The glands originate without doubt each from an epidermal cell, and assuming a long and club-like shape, have sunk deep into the subepidermal mesenchyme.

Right close to the internal surface of the basal membrane is the dermal musculature, which consists of the two systems of the external longitudinal and the internal circular muscle fibers (figs. 44 and 45, *l.m.* and *c.m.*). Both systems are made up of fine muscle fibers running closely side by side in a single layer.

Almost all the parts internal to the dermal musculature are occupied by the massive mesenchyme or the connective tissue, in which lie imbedded the pigments, the muscles of the deep parts, the nerves and all the rest of internal organs. Structurally, a distinction may be drawn between the mesenchyme of the periphery and that of the inner parts, although the two insensibly merge into each other. The latter forms by far the greater portion of the entire tissue. It is distinctly, though very loosely, fibrous, the fibers running mostly in the dorso-ventral direction. They are seen to be fine long processes, emanating directly from certain isolatedly situated cells—the connective-tissue cells (figs. 44, 46 and 47, *c.t.c.*)—which are either spindle-shaped and bipolar or irregularly shaped and multipolar, so to say. The fibers and cells lie in a space which appear to be occupied by a clear fluid, probably of a lymph-like nature. Occasionally met with in that space are roundish cells without processes and which may be identified as wandering cells (fig. 44, *w.c.*).

The mesenchyme of the periphery (fig. 44, *p.c.*), forming an indefinite, but on the whole thin, layer just beneath the dermal musculature, consists of rather closely disposed, irregularly shaped cells, which at places are apparently in direct fusion and

at other places are joined to one another by means of some short processes, leaving mesh-like spaces between them. The cytoplasm of the cells is deeply stained by eosin or erythrosin and shows a finely granular structure. The most deeply situated cells of the layer are not infrequently provided with longer processes than those more superficially situated, and that often in a less number,—thus approaching the form of the ramified mesenchyme cells in the deep parts of the proboscis. On the dorsal side of the proboscis, the continuity of the peripheral mesenchyme layer is much broken as seen on sections, on account of the presence of the club-shaped unicellular glands (figs. 43 and 45).

RIETSCH ('86) has described from *Bonellia minor* and *Thalassema neptuni* a subdermally situated layer of "cellules ganglionnaires," which occupy a position outside of the dermal muscle layers and which stand in direct connection with epidermal cells by means of fine processes. Now, the above described peripheral mesenchyme cells are not without resemblance to the "cellules ganglionnaires." Nevertheless, it seems not warranted to directly homologize the two, since the former are situated inside, instead of outside, the dermal muscular layers. Moreover, in *Th. tenuioides* the epidermis of the proboscis, unlike that of the body proper, is found to be everywhere separated from the underlying tissue by a distinct limiting membrane, and under no circumstance could a direct plasmic connection be demonstrated to exist between the two tissues.

In two ventral regions of the proboscis, the layer of the peripheral mesenchyme is specially thickened internally into a pair of massive, longitudinal bands (marked with + in fig. 43), which on transverse sections present a somewhat triangular outline and are conspicuous on account of an unusually dense

appearance of the tissue. The bands run all along the lateral margins of the proboscis, just beneath that ventro-lateral zone of the epidermis where this consists of considerably taller cells than in any other parts of it. The mesenchyme cells in the bands differ in no way from those in more strictly subdermal situations, but what gives to the tissue its distinctive appearance is the fact that the mesh-like intercellular spaces are taken up by the wandering cells present in a large number.

In the mesenchyme space, peripheral as well as deeply situated, are present pigment granules in abundance. To their peculiar distribution is due the brownish markings of the proboscis. Observed under the microscope, the granules are of various sizes and appear greenish yellow in color. They are generally arranged in irregular streaks, mostly around and along those connective-tissue fibers that extend in dorso-ventral direction in the thickness of the proboscis (fig. 44. *pg.g.*).

Of the muscles that traverse the mesenchyme space, there are to be mentioned, in the first place, those muscle fibers that run in the longitudinal direction. These are arranged in numerous, small and separately running bundles (figs. 44 and 47, *m.f.b.*), which show each a delicate sarcolemma-like envelope. Certain other muscle fibers, especially those that take dorso-ventral course, do not form themselves into bundles but run singly. Nevertheless, even these isolated muscle fibers can be readily distinguished from the connective-tissue fibers in that they show a finely fibrillar structure. A special system of fine muscle (fig. 43, *m.f.*) branch off from the circular system of the ventral dermal musculature, on each side of the proboscis at a point about midway between the lateral vessel and the lateral margin. It proceeds obliquely upwards and towards

the latter. In the course the single fibers somewhat diverge from one another; and after penetrating through the ventro-lateral mesenchymal band (+) spoken of before, they finally terminate under the thickened epidermis of the region. The system has certainly greatly to do with the incessant movements exhibited by proboscoidal margins of the living worm.

With respect to the nerves, I have nothing to add to what has been already known from other Echiuroids. Suffice it to say that there exists a pair of strong longitudinal nerves, the lateral nerves (fig. 43, *l.n.*), which join together near the apex of the proboscis, and that these lateral nerves at intervals of their course give off branches (*n.*) towards the sides. The branches again split into finer branches, which finally become lost from view in the subdermal tissues.

Of the blood-vessels, there are three, exactly as known from other Echiuroids. They are one median and two lateral vessels, all which, running longitudinally, become finally continuous with one another near the apex of the proboscis. As usual, the median vessel lies imbedded in the mesenchyme, while the thin-walled lateral vessel is contained within a continuation of the body-cavity, the so-called perihæmal cavity (fig. 43, *per.c.*).

The perihæmal cavity represents a moderately wide tubular space, running ventral to the lateral nerve. It is internally lined with the peritoneum consisting of somewhat flattened and stellate cells (fig. 46, *pr.*). Basally to the peritoneum is a very thin layer of circularly and longitudinally running muscle fibers. Now, the lateral vessel does not lie quite free in the perihæmal cavity, but is attached all along its dorsal line to the wall of the latter (fig. 46, *x*). Two flat epithelia (*ep.* and *ent.*) of quite similar appearance and an interposed thin layer of muscular

fibers (*m.f.*) constitute the wall of the vessel. The inner epithelium may with propriety be called the endothelium, while the outer is the continuation of the peritoneal lining of the perihæmal cavity. This structure of the vessel wall is clear in the present species, though it does not agree quite with our previous knowledge derived from other Echiuroids. Thus, RIETSCH ('86) says that in *Thalassema neptuni* and *Echiurus pallasii* the vessel wall is composed of only the peritoneal layer. SPENGEL ('80) states for the same of *Echiurus pallasii*: "Ich weiss nicht, ob eine innere Zellauskleidung vorhanden ist. Ich fand nur eine dünne Membran mit eingestreuten Kernen und in oder auf dieser liegend Muskelfasern, vorwiegend longitudinale Bündel bildend, und als äusserste Schicht einen Peritonealzellenbelag....." (*p.* 510). One sees at once that the "dünne Membran mit eingestreuten Kernen" in the above extract corresponds to the endothelial layer.

The median vessel of the proboscis is of essentially the same structure as is known from *Bonellia minor*, *Thalassema neptuni* and *Echiurus pallasii* (RIETSCH, '86), except in some not unimportant points. The reader is referred to fig. 47, which represents a part of a cross-section through the vessel in question. On the external side of the vessel wall and lying against the mesenchyme tissues (*c.t.c.*, *m.f.b.*), is a row of tall club-like cells arranged in an epithelium-like manner (*ept.*). They have the swollen and rounded end directed outwards, and sit with the opposite truncated end on a thin layer of circular muscle fibers. (*c.m.*). Some of the mesenchyme cells in the immediate surrounding are seen to insert their processes between the cells of the row. Inside the circular muscle fibers is a layer, which on cross-sections might at first sight be mistaken for an epithelium

consisting of cubical or cylindrical cells arranged in a row. What then appear like cells are in reality cross-sections of sarcolemma-like sheaths that inclose each a bundle of longitudinal muscle fibers (*l.m.*). In most places this layer forms apparently the innermost wall of the median vessel. A continuous endothelium could not be brought into view. However, there exist, here and there on the internal surface of the wall, peculiar isolated cells of irregularly stellate shape (*ent.c.*) They are fixed in position in that a part of their body is inserted in the interstice between the sarcolemma-like sheaths. If the cells can really be considered to constitute a part of the wall, they may possibly represent endothelial cells. In the proboscis of *Bonellia misakiensis*, which I studied for the sake of comparison, I found the median vessel as well as the lateral vessels provided with distinct endothelium. According to RIETSCH, neither an endothelium nor a layer of longitudinal muscle bundles, such as I have described, should exist in the wall of the median vessel in the proboscis of *Thalassema neptuni*, *Echiurus uncinatus* and *Bonellia minor*.

3. *Thalassema elegans* I. IKEDA.

(Fig. 4, Pl. I.; figs. 48 and 49, Pl. IV.)

1904. *Th. elegans*, I. IKEDA, Jour. Sci. Coll., Vol. XX., Art. 4, p. 65.

During July, 1902, I have obtained in all four specimens of this highly interesting species. At first it was thought they might possibly be the male of *Th. tenioides*, but a closer examination soon revealed the fact that I had before me a new

species allied to, but quite distinct from, the one just mentioned. *Th. elegans* inhabits the same shallow and muddy ground as *Th. tenuioides*, in the inlet of Moroiso, close to the Misaki Marine Laboratory. It lives in deep, vertically or somewhat obliquely sunk pits, which may be four feet deep and is scarcely distinguishable from those of *Th. tenuioides*. I must say, however, that I have never had an opportunity of discovering on the sea-bottom the external opening of the pit inhabited by the present species. Nor have I ever been able to see the outstretched proboscis of the worm on the bottom, notwithstanding the special searches I have made. This, coupled with the fact that the species so long escaped the notice of collectors in spite of the peculiar and conspicuous coloring of the proboscis, makes me think that the protrusion of this organ out of the hiding place, takes place under limited physical conditions, probably in the night time only.

As already indicated, the species is much alike *Th. tenuioides* in points of size, shape and color, though there exist remarkable differences in details and especially in the internal structure.

The proboscis, as measured on living specimens held in captivity, is 30–40 cm. long and 1.7–2 cm. broad in the broadest part, which is at the base. It is therefore considerably shorter and somewhat broader than in *Th. tenuioides*. The ground color is a clear yellow, which deepens in tone towards the base and along the free margin. The somewhat concave ventral aspect of the organ is marked in the distal parts with a fine and irregular network of a bright green color. The network is distinct for an extent of 6 cm. or more from the tip; proximally it grows gradually less distinct, at the same time assuming the form of fine transverse stripes. Finally, at about 15 cm. distance from the tip, the

marking disappears altogether. The ventral concavity of the proboscis deepens towards the base, so that in this region the organ presents the form of a half-tube semicircular in cross-section.

The cylindrical body proper measures 30–35 cm. in length and transversely 2.5 cm. across. The general color is a brownish red. Of the paler colored, equidistant, longitudinal lines due to special thickenings of the longitudinal muscle layer of the body-wall, there are ten, instead of five in which number they occur in *Th. tenuoides*. The dermal papillæ are in all respects similar to those of the species just referred to. They are largest and most closely aggregated in the anterior and the posterior parts of the body. Where the circular muscles of the body-wall has strongly contracted, there appear on the surface small lenticular outbulgings of the skin, regularly and closely arranged in longitudinal rows in the zones between every two of the ten pale-colored longitudinal lines. In the anterior half of the ventral side of the body, there are seen, in the living state, an indefinite number of deep red flecks which incessantly move about, at the same time changing their size (fig. 4). These flecks are brought about by the coming in contact of parts of segmental organs, which are of a milky white color, with the reddish inner surface of the body-wall. The two ventral hooks are situated a short distance—about 1.3 cm.—behind the base of proboscis. They are moderately large and slightly curved needles of a brownish yellow color. No anal hook is present.

Some Points of the Internal Structure.—All the longitudinal lines visible on the outside, excepting the one which runs in the mid-ventral line and is superposed by the nerve-cord, appear on

the inner surface of the body-wall as slightly elevated, narrow ridges or thickenings of the longitudinal muscular layer. In the ten zones separated from one another by the above lines, the circular muscle fibers form more or less regularly arranged transverse bundles. The basal parts of the muscular sheath of the ventral hooks are provided with numerous radial muscles, but there exists no interbasal muscle.

The entire *alimentary canal*, when stretched out straight, may be 210 cm. long in a large specimen. It pursues a complex and tortuous, but to a certain extent definite, course (fig. 49). The manner of its winding resembles that of many other Echiur-oids, especially of *Echiurus uncinatus* to my knowledge. As in this species, the entire canal is fixed to the body-wall by means of narrow muscular strands only, which are very numerous and of which the points of both origin and insertion are not in a straight continuous row but are distributed in different parts in relation with the convolution of the canal.

Here again, much difficulty is experienced in identifying the parts of the alimentary canal with those that have been distinguished by writers in other species. I can separate the canal into only three parts, *viz.*, the pharynx, the œsophagus and the intestine.

The *pharynx* (fig. 49, *ph.*) is a muscular tube, 4–5 cm. long and in the empty state about 5 mm. wide. Its inner surface is thrown into minute transverse folds. The posterior end of it is marked by the presence of the heart (*ht.*), situated on the dorsal side. No lateral mesenteries are present, but there exist some muscular strands that join the pharynx to the body-wall.

The *œsophagus* (*œs.*)¹⁾ is a somewhat narrower tube, measuring 25–30 cm. in length. Making turns backwards and forwards, it describes narrow S-like curves. The inner surface of the œsophagus is distinguished by the presence of closely set, villi-like protuberances, which look very much like those in the crop of *Th. tenioides*.

The *intestine* (*in.*) forms by far the largest part of the entire alimentary tract. It may be about 170 cm. long when stretched out straight, and is somewhat wider than the œsophagus, measuring on an average 8 mm. in width in the empty state. The transition of the œsophagus into the intestine is externally marked by the point of origin of the collateral intestine (*c.i.*). At first the intestine, as it starts from the last end of the œsophagus, is directed forwards in the anterior parts of the body on the left side. It then crosses over to the right side, above and across the pharynx. Thenceforth it runs posteriorly, pursuing an irregularly tortuous course, down to a point within a short distance from the posterior body end. Here it makes a sharp bend to continue its irregular winding course this time forwards. Coming up to a position in front of the first beginning of the intestine, it makes a second crossing over from left to right above the œsophagus. After that, it starts on the final, posteriorly directed, irregular course, which brings it to the terminally situated anus.

The *collateral intestine* (*c.i.*) is a moderately wide tube, running along the anterior parts of the intestine for a length of about 80 cm. The posterior parts of same, unaccompanied by the organ just mentioned, exhibit the siphonal groove (*s.g.*), which terminates behind in front of the rectum. This is about 1 cm.

1) In fig. 49, the first part of the œsophagus was inadvertently supplied with the reference *seg.*, which should be *œs.* instead.

long and is slightly dilated, being suspended on the lateral sides by an inconsiderable number of muscular strands.

The *anal glands* (*a.g.*), present in a pair on the sides of the rectum, are long and conspicuous tubular organs, which in large specimens may measure 20 cm. in length. The tube gradually narrows towards the tip. Only in the basal parts the organ is connected to the body-wall and the rectum by a few number of muscular strands; for the rest, it is entirely free. Over its entire surface are distributed numberless small and short-stalked funnels (fig. 48).

As before mentioned, the so-called *heart* (fig. 49, *ht.*) is situated dorsally on the hind end of pharynx. This anterior position of the heart constitutes one of the peculiarities of the species. On that account the dorsal vessel (*d.v.*) is rendered relatively short. The neuro-intestinal vessel (*n.i.*) arises from the ventral median point of the ring-sinus, which surrounds the extreme hind end of pharynx.

The *genital glands*, both male and female, develop, as in many other Echiuroids, from the peritoneum covering the posterior parts of the ventral vessel. In the present species, however, they do not form a specialized band lying on and along the ventral vessel, but cover the surface of the latter all around throughout their length. In all the four males and the single female I have obtained, the segmental organs were filled with fully mature reproductive elements of the respective sex. The spermatozoa are of a relatively large size, with head of an elongate conical shape. The eggs are spherical and relatively small in size.

The *segmental organs* present some very remarkable points, though, taken singly, they are of the ordinary type of structure. Each organ represents a conspicuous sac of an elongate club-like shape, tapering towards the inner end. It may be 3.5 cm. long and about 8 mm. broad at the bulbous base. The internal opening, present at the base, is provided with two, relatively short, spiral lobes.

The organs are present in a rather numerous number, though in a far less number than in *Th. tenuioides*. Moreover, the number varies with individuals and presumably also with the sex. In a general way I may say that it ranges from 13 to 27. The organs are by no means indefinite as to the mode of occurrence, but show a decided tendency towards a symmetrical and segmentally paired arrangement. Six or seven pairs of them may be distinguished, opening ventrally on both sides of the nerve-cord. The pairs are well separated and lie equidistant from one another, the first pair occurring only a short distance behind the mouth and the last pair behind the middle of the body. But it must be mentioned at once that the pairs are not always perfect nor strictly symmetrical with respect to the number of segmental organs composing each half-pair on either side of the ventral nerve-cord. Thus, while in some cases a pair consists of two segmental organs—one on each side of the body—and is thus perfect, in other cases a half-pair may consist of a group of 1–3 segmental organs, the number in each group varying in different pairs and very frequently also on the two sides of one and the same pair, which is thus rendered to consist of two symmetrical or assymetrical groups of the organs. It may even happen that a single organ exists on one side, but none on the other to complete a pair. Where more than one segmental organs occur in

a group to form a half-pair, they open close together apparently without a definite rule as to the relative position of the pores.

The exact manner of the grouping of segmental organs may be best seen from the following tables, which I have drawn up from four specimens available for the purpose.

Specimen A, ♂. (Dissection figured in fig. 49).

Order of pairs.	I.	II.	III.	IV.	V.	VI.	VII.	Total number of segm. bodies.
Number of segm. bodies on the right side.	1	1	1	2	1	1	1	21
Ditto on the left side.	1	2	2	3	3	2	0	

Specimen B, ♂. (Somewhat smaller than Spec. A).

Order of pairs.	I.	II.	III.	IV.	V.	VI.	VII.	Total number of segm. bodies.
Number of segm. bodies on the right side.	0	2	3	3	2	1	2	27
Ditto on the left side.	1	2	3	2	3	2	1	

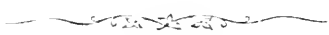
Specimen C, ♂. (Somewhat smaller than Spec. A).

Order of pairs.	I.	II.	III.	IV.	V.	VI.	VII.	Total number of segm. bodies.
Number of segm. bodies on the right side.	1	1	2	3	2	1	1	25
Ditto on the left side.	1	3	3	2	1	2	2	

Specimen D, ♀. (The single female at disposal).

Order of pairs.	I.	II.	III.	IV.	V.	VI.	VII.	Total number of segm. bodies.
Number of segm. bodies on the right side.	2	1	1	1	1	1	0	13
Ditto on the left side.	1	1	1	1	1	1	0	

Noteworthy is the fact that in Specimen A, the first pair of segmental organs lies just behind the ventral hooks; whereas in all the other specimens I have found it situated in front of the hooks. It seems then assumable that the pair which presents itself as the first and the anteriormost in some individuals is entirely lost in others. In this respect, Specimen B may be considered to represent in a way a stage in which the pair in front of the ventral hooks is on the way of disappearing, that pair in the said specimen being represented by a single segmental organ on the left but by none on the right side. This way of looking at things leads one further to infer that the posteriormost pair is also disappearing; the process seems to stand on the way of progress in Specimen A, and to be consummated in Specimen D, as will be clear from a comparison of the above tables referring to the specimens in question. Granting that the segmental organs in the present species show signs of having undergone numerical diminution, it may be admissible to assume that the state of their pairwise or pseudo-pairwise arrangement has been derived from the condition obtaining in *Th. tanioides*, in which the organs in question occur crowded together without apparent order. In support of this view may be adduced the fact that whenever more than one segmental organs from a half-pair group in the present species, they are grouped together without a definite rule as to their relative position. Anyway, with respect to the number and the mode of arrangement of segmental organs, the present species may be said to stand in a measure intermediate between *Th. tanioides* and other Echiuroids with only 1-3 pairs of that organ.



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Explanation of Plates.

Explanation of Index Letters.

<i>a.g.</i>anal gland.	<i>h.b.</i>bulbular portion of ventral hooks.
<i>b.c.</i>coelomic corpuscle.	<i>ht.</i>heart.
<i>c.</i>body-cavity.	<i>i.m.</i>interbasal muscle of ventral hooks.
<i>c.i.</i>collateral intestine.	<i>in.</i>intestine.
<i>c.m.</i>circular muscle.	<i>li.m.</i>limiting membrane beneath epidermis.
<i>cr.</i>crop.	<i>ll.</i>trabecular layer of pharyngeal wall.
<i>ct.</i>cuticle.	<i>l.m.</i>longitudinal muscle.
<i>c.t.c.</i>connective-tissue cell.	<i>ln.</i>lateral nerves of proboscis.
<i>c.t.l.</i>connective-tissue layer.	<i>ls.</i>lactunar space.
<i>cts.</i>cutis.	<i>lv.</i>lateral vessels of proboscis.
<i>d.m.</i>suspensory membrane of the dorsal vessel.	<i>mf.</i>muscle-fibre.
<i>d.v.</i>dorsal vessel.	<i>mf.b.</i> ...muscls-fibres in bundles.
<i>ent.</i>endothelium.	<i>mg.</i>midgut.
<i>ep.</i>epidermis. In fig. 46, peritoneal layer of the wall of lateral vessel.	<i>m.m.</i>mucous membrane.
<i>ept.</i>epithelium.	<i>mp.</i>muscular pads.
<i>ex.o.</i>external orifice of segmental organs.	<i>n.</i>nerve.
<i>fn.</i>funnels of anal glands and vas deferens.	<i>n.c.</i>nerve-cell.
<i>g.gl.</i>large unicellular glands.	<i>ni.</i>neuro-intestinal vessel.
<i>gl.</i>unicellular glands in body-wall and alimentary canal.	<i>æs.</i>oesophagus.
<i>gl.s.</i>gland-like structure of the ventral mesentery suspending the crop.	<i>o.m.</i>oblique muscle.
	<i>p.c.</i>peripheral mesenchyme cells.
	<i>per.c.</i>perihæmal cavity of proboscis.

<i>pf.</i>pigment-bodies.	<i>sp.</i>spermatozoa.
<i>pf'.</i>pigment-like bodies in cutis.	<i>tl.</i>trabecular layer.
<i>pg.g.</i>pigment granules.	<i>ts.</i>typhlosole-like ridge in ces-
<i>ph.</i>pharynx.	ophagus.
<i>pw.</i>peritoneum.	<i>v.</i>vacuole-like spaces.
<i>r.m.</i>radial muscles of ventral	<i>vd.</i>vas deferens.
hooks.	<i>vm.</i>ventral mesentery.
<i>r.v.</i>ring vessel.	<i>vn.</i>ventral nerve-cord.
<i>seg.</i>segmental organs.	<i>vv.</i>ventral vessel.
<i>s.g.</i>siphonal groove.	<i>w.c.</i>wandering cells.
<i>s.m.</i>sperm-mass.	<i>w.m.</i>wing-muscles of pharynx.
<i>s.o.</i>sensory organ.	



Plate I.

Fig. 1.—*Bonellia miyajimai* (female). $2\times$.

Fig. 2.—Male of *Bonellia miyajimai*. From a photograph. $1\frac{1}{4}\times$.

Fig. 3.—*Thalassema tenuioides*. Drawn from a small specimen in the living state. Nat. size.

Fig. 4.—*Thalassema elegans*. Anterior half of the body proper with the proboscis, in the living state. Nat. size.

Plate II.

(Figs. 5-17, *Bonellia miyajimai*.)

- Fig. 5.—Magnified figure showing the two muscular pads (*m.p.*) enclosing the roots (*h.b.*) of ventral hooks, together with the ventral vessel (*v.v.*) and the ventral nerve-cord (*v.n.*) as seen from inside of the body-wall. A number of radial muscles (*r.m.*) radiate from the periphery of the pads.
- Fig. 6.—Ventral hooks seen from the external surface of the body. About 65 ×.
- Fig. 7.—One of the primary branches of the anal gland, giving off numerous secondary branches, each of which ends in a small funnel (*fn.*). About 40 ×.
- Fig. 8.—Part of a paratangential section of the body-wall of the male (near the posterior body end), slicing the epidermis (*ep.*) and the dermal muscular layers. The epidermis is cut obliquely, so that its one-cell layered structure is made obscure. The small roundish or oval spaces (*l.s.*) among the dermal muscular fibres (*c.m.*, *l.m.*) are lacunar spaces which form an anastomosing network continuous with some of the subdermal trabecular layer. About 180 ×.
- Fig. 9.—Part of a horizontal section of the body-wall of the male, passing partly through the ventral nerve-cord (*v.n.*) and partly just below it where the oblique muscle-layer (*o.m.*) is much thickened. About 180 ×.
- Fig. 10.—Transverse section through the anterior region of the male, passing through the anterior swollen extremity of the ventral nerve-cord (*v.n.*). The section also shows the vas deferens (*v.d.*) and the narrow body-cavity (*c.*), both cut across near their anterior end. About 180 ×.
- Fig. 11.—Part of a transverse section through the body of the male in about the middle of the anterior one-eighth of its length, in which region the vas deferens (*v.d.*) is somewhat widened and its position slightly raised so as to project into the body-cavity (*c.*). About 180 ×.
- Fig. 12.—Highly magnified figure representing a transverse section through the ventral nerve-cord (*v.n.*) and the vas deferens (*v.d.*). The latter is here divided into three canals, all which are still con-

tained in a common connective-tissue ridge, projecting prominently into the body-cavity (*c.*). Zeiss, oc. 2 and hom. imm. $\frac{1}{12}$.

Fig. 13.—Part of a transverse section of the male, passing through the posterior portion of the anterior one-eighth of the body. Two (I and II) of the four terminal branches of vas deferens are seen free in the body-cavity. About $65\times$.

Fig. 14.—Sections of the tubular terminal branches (four in number) of the vas deferens. All the branches lie free in the body-cavity; they are cut through in various directions. Zeiss, oc. 3 and obj. E.

Fig. 15.—Cross-section through a ciliated funnel of the vas deferens, close to the inner end. As the result of preservation, the funnel has lost its natural shape and the section is seen to have passed at two opposite places through the parts where the inner and outer epithelia are directly continuous. About $410\times$.

Fig. 16.—Highly magnified figure showing a sperm-cell mass (*s.m.*) together with the underlying ventral nerve-cord (*v.n.*), both in cross section. The sperm-cell mass is fixed to the body-wall over the nerve-cord by a short mesentery-like stalk. Zeiss, oc. 2 and hom. imm. $\frac{1}{12}$.

Fig. 17.—Part of the wall of the vesicular body, representing the degenerated alimentary canal of the male. The inner epithelial cells (*ept.*) are vacuolated and are provided at the inner end with pseudopodia-like processes. Zeiss, oc. 2 and hom. imm. $\frac{1}{12}$.

(Figs. 18—22, *Thalassema twinioides*.)

Fig. 18.—Anterior part of a dissected specimen, showing, among other things, segmental organs *in situ*. In the regions marked with *, a number of the organs have been cut off at the roots, in order to show the manner of their arrangement. About $1.5\times$.

Fig. 19.—Same as above, to show the anterior courses of the dorsal (*d.v.*), and the ventral vessel (*v.v.*), and also the ring vessel (*r.v.*). The ring vessel runs over and beyond the interbasal muscle (*i.m.*) of the ventral hooks; at the proboscis basis it divides into three short branches, for which see the following figure. $2\times$.

Fig. 20.—Greatly magnified figure representing the manner of communication between the bases of the two lateral vessels (*l.v.*) of proboscis and the three anterior branches of the ring-vessel (*r.v.*) mentioned above.

Fig. 21.—Corpuscular bodies floating in the coelomic fluid. *a*, surface

view of irregularly lobed cells composing the wall of a very large corpuscular body. *b*, an entire small corpuscular body consisting of only four cells yet without lobe-like processes. 410 ×.

Fig. 22.—Optical longitudinal section of a "*Töpchen*." Zeiss, oc. 2 and hom. imm. $\frac{1}{12}$.

Plate III.

(All figures in this plate refer to *Thalassema tainioides*.)

Fig. 23.—Internal anatomy of a female specimen. The body-wall was cut open along the mid-dorsal line to expose the viscera into view. Reduced to $\frac{7}{10}$ natural size.

Fig. 24.—Some segmental organs greatly magnified. Each organ consists of a basal tubular portion, a swollen portion containing numerous eggs and of the ciliated funnel.

Fig. 25.—Magnified view of ciliated funnel-tubes on the surface of anal gland. Some tubes stand single, while some others are branched, each branch ending with a funnel.

Fig. 26.—Part of the body-wall from a transverse section, passing through nearly the middle of a small papilla. 180 ×.

Fig. 27.—Part of a section through a small papilla under higher magnification than in fig. 26, to illustrate the finer structure of the peripheral parts. Zeiss, oc. 4 and hom. imm. $\frac{1}{12}$.

Fig. 28.—Part of a section through a large papilla. In the cutis-layer are imbedded numerous large unicellular glands (*g. gl.*), distinctly opening each for each through the epidermis on the cuticular surface. Zeiss, oc. 2 and hom. imm. $\frac{1}{12}$.

Fig. 29.—Median part of a transverse section through the ventral body-wall. Some segmental organs are seen in section on both sides of the ventral nerve-cord. Zeiss, oc. 2 and obj. a_2 .

Fig. 30.—Part of a longitudinal section of the wall of a segmental organ near its external opening. Owing to abundance of large unicellular glands, the epithelial wall in this region is conspicuously thickened, as shown also in the preceding figure (*ex.o.*). Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Fig. 31.—Part of a longitudinal section of the wall of the tubular portion of a segmental organ. Between the two epithelial layers (the

peritoneum *pr.* and the inner epithelium *ept.*), there exists a connective-tissue layer comprising the internal longitudinal (*l.m.*) and the external oblique muscles (*o.m.*). Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Fig. 32.—Part of pharyngeal wall and of muscular lateral mesentery (*w.m.*) in transverse section. Circular folds of the mucous membrane (*m.m.*) and the muscular arrangement are well seen. About $40 \times$.

Fig. 33.—Small part of the pharyngeal mucous membrane greatly magnified. Unicellular glands (*gl.*) are interposed between strongly compressed epithelial cells (*ept.*). Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Fig. 34.—Highly magnified figure showing the structure of the trabecular layer in the pharyngeal wall; taken from a cross-section. In the lacunar spaces (*l.s.*) are contained amoeboid cells (*w.c.*). Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Fig. 35.—Cross-section of the anterior portion of oesophagus with the typhlosole-like ridge (*ts.*). *w.m.* (misprinted *v.m.* in the plate) in this figure indicates the posterior continuation of the right lateral mesentery. $56 \times$.

Fig. 36.—Showing the histological structure of the typhlosole-like ridge of oesophagus. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Plate IV.

(Figs. 37–47, *Thalassema tainioides*. Figs. 48 and 49, *Thalassema elegans*).

Fig. 37.—Cross-section of the crop and of the ventral mesentery (*v.m.*), on which a gland-like structure (*gl.s.*) is developed. About $40 \times$.

Fig. 38.—Part of the crop-wall in cross-section. The villi-like prominences of the mucous membrane are seen to be composed of a syncytial mass of protoplasm. Peritoneum (*pr.*), peculiarly modified, consisting of tall cells. Longitudinal and circular muscle layers in reversed order against same in pharynx and oesophagus. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

Fig. 39.—Part of a cross-section through the gland-like structure of the ventral mesentery. Above, two side-folds of the mesentery proper (A,B). *a* (*pr.*) and *b* (*pr.*) indicate two forms of the peritoneal cells. *b.c.*, celomic corpuscles, probably derived from the peritoneal cells. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.

- Fig. 40.—A small part of the midgut in cross-section. Only one of the epithelial folds is shown. The peritoneal lining (*pr.*) consists of moderately tall cells in a row. Relative position of the two muscular layers (*c.m.* and *l.m.*) as in crop. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 41.—Highly magnified figure of a part of the wall of collateral intestine in cross-section. Only one of the folds is shown. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 42.—Part of a longitudinal section through the wall of ventral vessel. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 43.—Left marginal portion of proboscis in cross-section. 65 \times .
- Fig. 44.—Ventral part of a cross-section through proboscis. On this side the epidermis is ciliated. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 45.—Dorsal part of a cross-section through proboscis. On this side the surface is not ciliated; numerous unicellular glands (*g.gl.*) are present seated deeply in subdermal mesenchyme. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 46.—A small part of a cross-section through proboscis, showing the relation of the perihæmal cavity (*per.c.*) to the lateral vessel (*l.v.*) and also the histology of the region. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 47.—Greatly magnified figure of a part of a cross-section of the median vessel of proboscis. Zeiss, oc. 2 and obj. hom. imm. $\frac{1}{12}$.
- Fig. 48.—Magnified figure showing a number of ciliated funnels (*fu.*) situated on the surface of anal gland in *Thalassema elegans*.
- Fig. 49.—A specimen of *Th. elegans* dissected to show the internal organs *in situ*. The body-wall has been cut open along the dorsal median line. Reduced to $\frac{3}{4}$ natural size.





Fig. 5

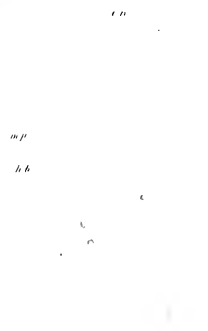


Fig. 6

mp
hb



Fig. 10

Fig. 6



Fig. 7

Fig. 11



Fig. 9



Fig. 19



Fig. 18

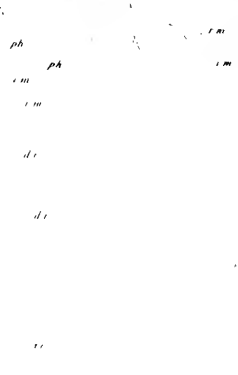


Fig. 12



Fig. 17



Fig. 15



Fig. 14



Fig. 13

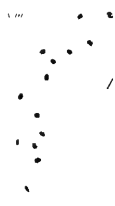


Fig. 21a



Fig. 16



Fig. 20



Fig. 21b



Fig. 22

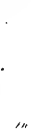


Fig. 23.



Fig. 24.



Fig. 25.



Fig. 26.

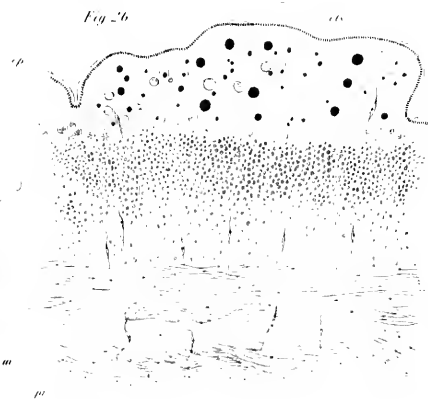


Fig. 27.

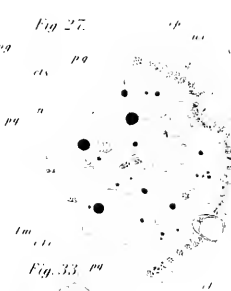


Fig. 28.

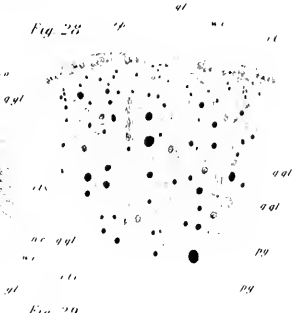


Fig. 29.

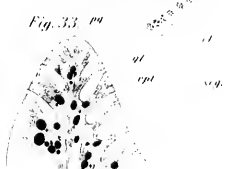


Fig. 30.

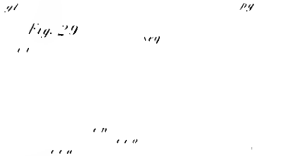


Fig. 31.



Fig. 32.



Fig. 33.

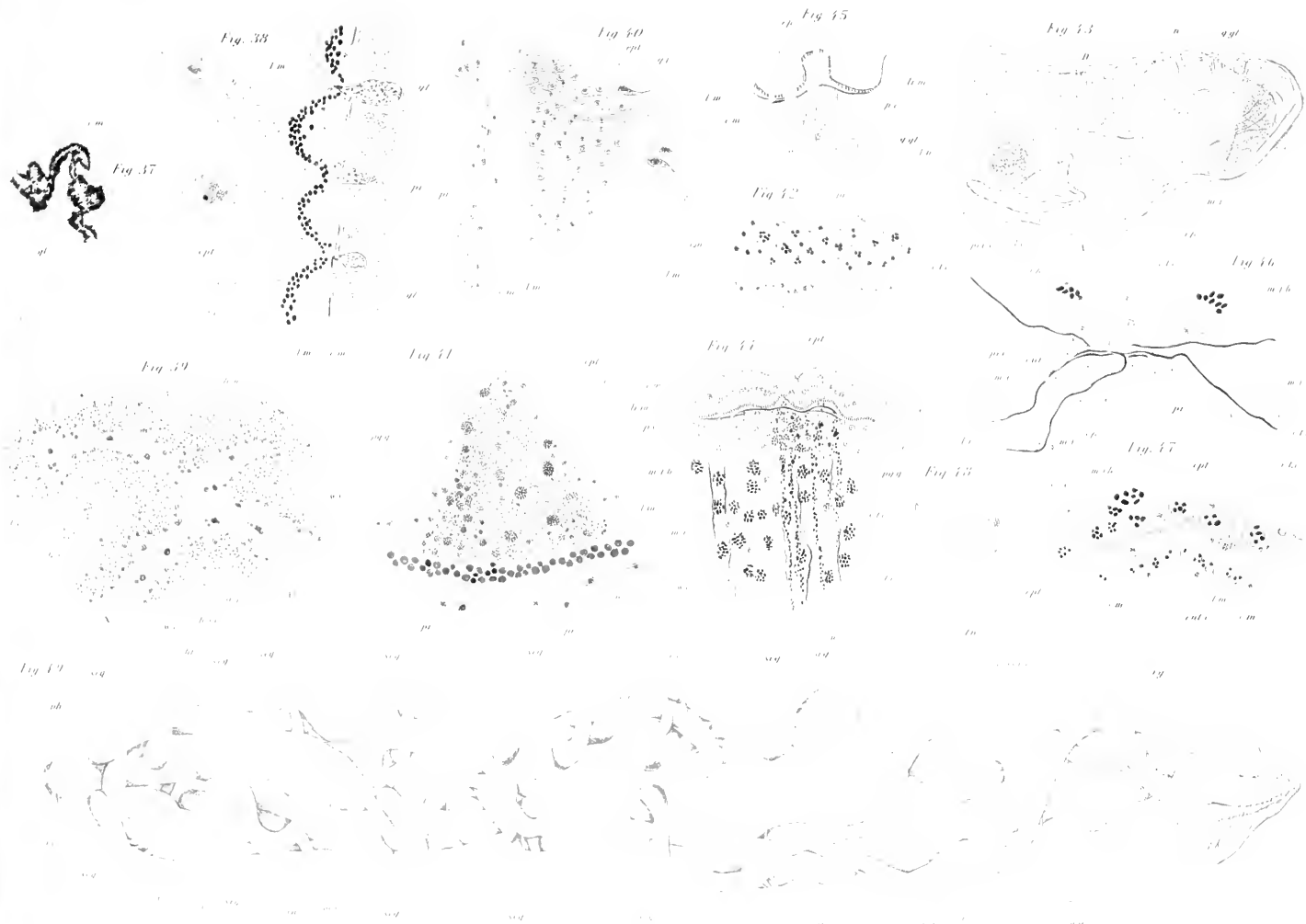


Fig. 34.



Fig. 35.





Mesozoic Plants from China.

15

ERRATA FOR ART. 9, VOL. XXI.

(YOKOYAMA, MESOZOIC PLANTS FROM CHINA).

On pp. 2-4, 11, 18, 20, 35, 37, in the table and in the explanations for plates, Ssu-ch'uang is to be read *Ssu-ch'uan*.

P. 5, l. 7. Read 3. instead of 4.

P. 6, l. 13. Read *P'ing-hsiang-Hsien* instead of P'ing-hsian-Hsien.

P. 8, l. 11. Read *Hsüan-hua-Fu* instead of Hsuan-hua-Fu.

P. 35, l. 2, in the table and in the explanations for plates, read *Shi-kuan-tzu* instead of Shi-huan-tzu.

of Shan-tung²⁾ and Chih-li.³⁾

1) 江西. Often written Kiangsi.

2) 山東.

3) 直隸

Mesozoic Plants from China.

By

Matajiro Yokoyama, *Rigakuhakushi.*

Professor of Paleontology, Imperial University of Tokyo.

With 12 plates.

1. GENERAL REMARKS.

The greater willingness, recently shown by the Chinese to have the mineral resources of their country investigated by the Japanese, naturally led several of our scientific men to avail themselves of the opportunity to explore the mines and coal-fields of the interior of that bulky empire.

Between the years 1899 and 1900, Mr. T. HIRABAYASHI, now Assistant Professor in the Engineering College of Tokyo, visited the province of Chiang-hsi,¹⁾ and during his six months stay there made many valuable geological observations.

In 1902, Messrs. T. WADA, T. Ogawa and N. KANEHARA, all geologists, examined the mines of Northern China, especially those of Shan-tung²⁾ and Chih-li.³⁾

1) 江西. Often written Kiangsi.

2) 山東.

3) 直隸

In the following year, Prof. K. YAMADA of the Kyoto University, explored South-western China, penetrating into the provinces of Ssu-ch'uang¹⁾ and Yün-nan.²⁾

Also during and after the late Manchurian campaign, many of our geologists went to investigate the mineral wealth of Southern Manchuria then occupied by our army. They were Messrs. T. OGAWA, K. INOUE, N. KANEHARA, N. FUKUCHI and C. ŌINOUE, most of whom belong to the Imperial Geological Survey of Japan.

Among the many valuable scientific prizes brought back by these men, are the fossil plants collected in coal-mines, and therefore directly available for determining their geological age. The greater part of these plants belong to those of the Mesozoic era, while others are either those of the Carboniferous or of the Tertiary period. The task of examining these fossils, I took upon myself, and the following are results obtained from my study of the Mesozoic forms.

The Mesozoic flora of China is already known from the works of SCHENK, KRASSER, ZEILLER, NEWBERRY, and others; but as the plants described in this paper all come from new localities, I hope they will add not a little to the knowledge of the Chinese flora of this formation.

The plants belong to three distinct periods of the Mesozoic, so that they may be treated under three distinct headings.

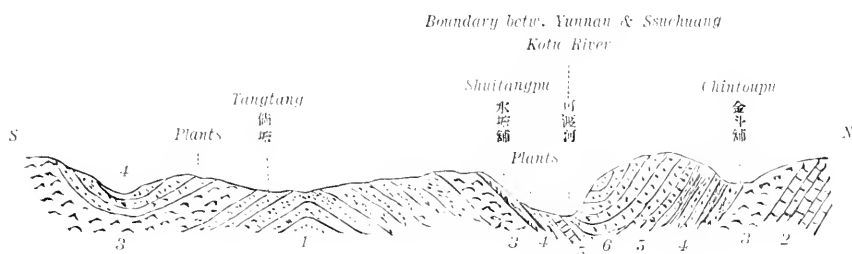
1) 四川. Also written Sechwan, Sztswan, etc.

2) 雲南.

It is here to be noted that the Chinese names of places are pronounced more or less differently in the different parts of the Empire. But for the sake of uniformity, they are all written herein as they are pronounced according to the official dialect of Peking, and the mode of representing them in Roman letters followed in this paper is that proposed by THOMAS WADE.

I. TRIASSIC PLANTS.

These were brought back by Prof. YAMADA from two places in Yün-nan, viz. Tang-t'ang¹⁾ and Shui-t'ang-p'u,²⁾ very near each other and quite near the boundary of Ssu-ch'uang. The distance between these two places may be from 15 to 16 kilom. The following is a rough geological profile constructed according to a sketch-map by Prof. YAMADA.



1. Sandstone probably of Palaeozoic age.
2. Limestone (Permo-Carboniferous?)
3. Diabase and its tuffs.
4. Red and green sandstones and shales, containing fossil plants; and near Shui-tang-pu a coal seam.
5. Limestone.
6. Red and yellow sandstones and shales probably belonging to a formation constituting the Mesozoic Basin of Ssu-ch'uang, the greater part of which seems to be Jurassic.

The number of species brought back from Yün-nan is small. From Tang-t'ang we have

1. *Angiopteridium* cf. *infarctum* FEISTM.
2. *Cladophlebis* sp.
3. *Carpolithes Yamadai* n. sp.

Besides, there is an imperfect fragment of a fern which seems to be a species of *Glossopteris*. From Shui-t'ang-p'u, we have

1) 陶塘

2) 水塘舖

1. *Angiopteridium cf. infarctum* FEISTM.
2. *Clathropteris* SP.
3. *Phœnicopsis? Yamadai* N. SP.

These plants are contained in a fine-grained greenish grey sandstone in which the venation of the leaves is for the most part imperfectly preserved, so as to make their determination extremely difficult. Notwithstanding this fact, the presence of *Angiopteridium cf. infarctum* FEISTM. in the florulas of the two places shows that in all probability they belong to the same geological horizon.

As to the age of the plant-bearing rocks, the only species available in determining it is the above mentioned *Angiopteridium*. *Angiopteridium infarctum* is a form described from the Upper Gondwana of India which belongs to the Triassic. Therefore it is most likely that the Yün-nan plants represent some part of the Triassic. Whether they are contemporaneous with the Rhætic forms described by Prof. ZEILLER from Tai-p'ing-ch'ang, a place more to the west in Yün-nan still remains to be confirmed.

II. JURASSIC PLANTS.

By far the greater part of the fossils treated in this paper belong to the Jurassic. They are from five provinces, or Shêngs, as they are called by the Chinese.

A. Ssu-ch'uang-Shêng.¹⁾

The plants come from three places in this province, and all were collected by Prof. YAMADA.

1) 四川省

a. Ch'ing-kang-lin, P'êng-Hsien.¹⁾

The plant-bearing rock is a dark grey argillaceous sandstone, with fine glittering pieces of mica. The preservation is excellent. The species of plants found here are three, viz.:

1. *Todites Williamsoni* (BRONGN.).
2. *Podozamites lanceolatus* (LINDL. et HUTT.).
4. *Antholites chinensis* n. sp.

Todites Williamsoni is a widely distributed Middle Jurassic fern, and *Podozamites lanceolatus* is also a form, chiefly occurring in the same formation. Therefore there is hardly any doubt about the plant-bed being Jurassic. And so is the next locality.

b. Ta-shih-ku, Pa-Hsien, Chung-ching-Fu.²⁾

The plants are found in a dark shale having an imperfect platy structure. Their preservation is very good. We have only two forms.

1. *Todites Williamsoni* (BRONGN.).
2. *Carpolithes globularis* n. sp.

c. Lung-wang-tung, Chiang-pei-Ting.³⁾

From this place we have only two small fragments of Equisetaceæ in a dark micaceous shale. One specimen resembles *Schizoneura hoerensis* HISINGER. This species is a plant found in the Rhætic as well as in the Jurassic, and as it occurs also in the latter formation of Sai-ma-chi⁴⁾ in Southern Manchuria, I consider it not improbable that the plant-bed of Lung-wang-tung belongs to the same formation as the above two places in Yün-nan.

1) 彭縣青崗林.

2) 重慶府巴縣大石鼓.

3) 江北縣龍王洞.

4) 賽馬集.

B. Chiang-hsi-Shêng.¹⁾

The plants of this province were all collected by Mr. HIRABAYASHI who found them in shales in coal-mines. These shales are all of nearly similar character, being dark, more or less soft and imperfectly cleavable, except the one from Ch'ung-chia-fang, which is coaly and black, and harder than the others. The plant-species are very few, probably not because they are rare, but because the collector had not time to gather a large number of them. Of the six localities, those which show only a single species of *Podozamites lanceolatus* (LINDL. et HUTT.) are the following three.

- a. San-chia-chung, An-yüan, P'ing-hsiang-Hsien.²⁾
- b. Kao-kang, P'ing-hsian-Hsien.³⁾
- c. Ch'ung-chia-fang, I-ch'un-Hsien.⁴⁾

The place called

- d. Sha-shih-chieh, An-yüan, P'ing-hsiang-Hsien,⁵⁾

has given, besides *Podozamites lanceolatus*, a species of *Ginkgoaceae* called *Phœnicopsis latior*, a plant widely distributed in the Jurassic of Siberia. At

- e. Ssu-lu-pu, Hsing-an-Hsien,⁶⁾

there are only two indeterminable *Cycads*, *Pterophyllum* and *Nilssonia* the former of which however shows some resemblance to that already found in the Jurassic of other parts of China. Also at

1) 江西省.

2) 萍鄉縣安源三夾沖.

3) 萍鄉縣高坑.

4) 宜春縣鐘家坊.

5) 萍鄉縣安源沙市界.

6) 興安縣司路舖.

f. Liao-chia-shan, Fêng-ch'êng-Hsien¹⁾

there is only a *Cladophlebis* which is not determinable, although it presents some resemblance to the Jurassic forms.

Of these six localities, the only one which is undoubtedly Jurassic is Sha-shih-chieh. Probably so are also the three places which have yielded *Podozamites*, while the last two, palaeontologically speaking, can be described simply as Mesozoic. Mr. HIRABAYASHI, however, from the geological point of view, considers the six coal-mines above enumerated as belonging to one and the same formation.

C. Shan-tung-Shêng.²⁾

The plants from this province were collected in the coalmine of Fang-t'u in Wei-Hsien³⁾ by Mr. WADA who visited the place in 1902 in company with Messrs. OGAWA and KANEHARA. A large slab of a grey argillaceous sandstone, together with some smaller ones sent to me by Mr. WADA, contain fossils in excellent preservation which belong to the following four species:

1. *Todites Williamsoni* (BRONGN.).
2. *Coniopteris hymenophylloides* (BRONGN.)
3. *Ctenis* sp.
4. *Podozamites lanceolatus* (LINDL. et HUTT.).

Of these four, the three which are specifically determined are well-known Jurassic forms, and *Ctenis* which I have left undetermined on account of its fragmentary character also presents some resemblance to one of the forms called *C. Zeuschneri* RACH. occurring in the Jurassic of Poland. Therefore it is quite certain

1) 豐城縣廖家山.

2) 山東省.

3) 濰縣坊士(或ハ房士トモ云フ).

that we have here a formation which represents the middle portion of the Mesozoic Group.

RICHTHOFFEN in the second volume of his "China" refers to a coal-field situated south of Wei-hsien which certainly includes the mine of Fang-t'u. He took it for Carboniferous (China II, p. 227), an error which arose from his thinking that it belonged to the same geological formation as the Sinian which occurs very close to it.

D. Chih-li-Shêng.¹⁾

Mesozoic plants were collected only in a single locality, viz. ;

Lao-tung-ts'ang, Hsuan-hua-Fu.²⁾

According to Mr. OGAWA who made this collection, the coal-bearing strata of this place are sandstones and shales, overlaid by a conglomerate composed of pebbles of porphyrite and presenting a tuffy character. Their strike is said to run parallel to the mountain-range of Chi-ming-shan which takes a east-north-east and west-south-west direction, and is made up of highly contorted layers of the platy sandstones, white limestones, etc. of the Sinian formation. The geological profile is as given below.



1. Sinian Formation (Plakozoic).
2. Conglomerate consisting of porphyrite-pebbles.
3. Coal-bearing Series.
4. Loess.
5. Young Quaternary river-gravel.

1) 直隸省.

2) 宣化府老東營.

The plants occur in dark-grey, banded, sandy shales, and are tolerably well preserved. They belong to two species, viz.:

1. *Coniopteris hymenophylloides* (BRONGN.)
2. *Ginkgo flabellata* HEER.

The first occurring in the Middle Jurassic of Europe, Siberia, Japan etc. and the second also in that of Siberia, there is no doubt about the coal-field of Lao-tung-ts'ang belonging to the same formation.

RICHTHOFFEN had already taken this coal-field for Jurassic, not from plants found at Lao-tung-ts'ang, but probably from those which he collected at Tshai-tang,¹⁾ lying to the south of the above place.

E. Shêng-ching-Shêng.²⁾

Plants were collected at the following four places:

a. Nien-tzu-kou, Sai-ma-chi.³⁾

The collector, Mr. KANEHARA, went to Nien-tzu-kou to examine the coal-field. The plants are contained in a brittle shale, dark grey to blackish, sometimes slightly reddish. They are generally well preserved, although rarely they are quite carbonized. The following forms have been distinguished:

1. *Schizoneura hoercensis* HISINGER.
2. *Todites Williamsoni* (BRONGN.).
3. *Ctenis Kaneharai* n. sp.
4. *Ginkgo lepida* HEER.
5. *Baiera gracilis* BUNB.

1) 齋堂 Chai-t'ang according to the Peking official dialect.

2) 盛京省.

3) 賽馬集碱子溝.

6. *Czekanowskia Murrayana* (LINDL. et HUTT.).

7. *Palyssia manchurica* n. sp.

Todites Williamsoni, *Ginkgo lepida*, *Baiera gracilis*, and *Czekanowskia Murrayana* are true Middle Jurassic forms. *Schizoneura hoerensis* is a species occurring in both the Jurassic and the Rhætic of Europe, while *Palyssia manchurica* has its nearest allies in forms found in the Indian Jurassic and the European Rhætic. Therefore it is quite certain that the plant- and coal-bearing series of Nien-tzu-kou belongs to the Middle Jurassic.

b. Sha-ho-tzu, Ch'ang-tu.¹⁾

From this locality, Mr. OGAWA brought several pieces of a fine-grained yellowish sandstone, containing several fragments of plants which belong to a single species of *Dioonites Brongniarti* (MANT.). This *Cycad* which was first found in the Wealden of Europe has also been found in the Jurassic of Japan. Therefore the coal-bearing layers of Sha-ho-tzu in which it was found probably belong to the same formation.

c. Ta-t'ai-shan, Ch'üan-yen-kou.²⁾

From the coal-mine of this place, Mr. OGAWA brought a thinly cleavable, brittle, grey shale containing several fragments of plants which belong to two species, viz.

1. *Podozamites lanceolatus* LINDL. et HUTT.

2. *Ginkgo* sp.

The first, as has already been stated several times, is a widely distributed Jurassic species, although it occurs also in the layers above as well as in those below this formation. Of the second species the specimens are all fragmentary and not determinable.

1) 昌圖沙河子.

2) 泉眼溝大台山.

with any degree of certainty; still it seems to be a form undoubtedly belonging to those found in the Jurassic. Therefore we may fairly assert that we have here a formation which probably corresponds to the one above named.

d. Pao-êrh-shan.¹⁾

A piece of light grey sandy shale, found by Mr. OGAWA in the coal-mine of the above place, contains numerous fragments of roots of an Equisetaceous plant which, however, resemble those of *Phyllothea sibirica* HEER of the Siberian Jurassic, and which I have therefore called *Phyllothea* sp. Also a small fragment of a pinna of a *Cladophlebis* was found with acute pinnules. But it is so imperfect that it can not be determined with any degree of accuracy. On this account, I leave the age of this coal-bearing formation undetermined, although presumably it is also Jurassic.

III. Cretaceous Plants.

At two places in the Mesozoic Basin of Ssu-chuang, Prof. YAMADA collected plants which are decidedly younger than those found in other localities. These two places are called Shi-kuan-tzu and Sha-chi-miao.

a. Shi-kuan-tzu, Chao-hua-Hsien.²⁾

This place lies north-east of Ching-tu-Fu³⁾ the capital of the province, and very near the northern boundary of the Mesozoic Basin. The plant-bearing rock which occurs together with coal-seams is a dark grey friable shale, in which the plants seem to

1) 抱兒山.

2) 昭化縣石鑽子.

3) 成都府.

be tolerably numerous. The species, however, which I have been able to distinguish number only three, viz.:

1. *Coniopteris nitidula* n. sp.
2. *Glossozamites Hoheneggeri* (SCHENK).
3. *Podozamites lanceolatus* (LINDL. et HUTT.).

Glossozamites Hoheneggeri is a species hitherto found only in the Wernsdorf beds of the Northern Carpathians; while *Coniopteris nitidula*, although new, shows a great affinity to *C. Cordai* (SCHENK) of the German Wealden. *Podozamites lanceolatus* is a form ranging from Rhætic to Cenomanian. Therefore it is fairly certain, that we have here a formation which corresponds to the Neocomian of Europe.

b. Sha-chi-miao, Ho-Chou.¹⁾

This place is situated to the east of Ching-tu-Fu, and in the midst of the Mesozoic Basin. The plants are imbedded in a light grey cleavable shale, associated with the coal-layers of the district. The specimens belong to the following three species:—

1. *Cladophlebis* sp.
2. *Glossozamites Hoheneggeri* (SCHENK).
3. *Glossozamites acuminatus* n. sp.

A glance at these forms immediately suggests the same formation as at Shi-kuan-tzu, especially as the genus *Glossozamites* occurs mostly in the Lower Cretaceous.

Tabular View of the Mesozoic Plants.

I. TRIASSIC PLANTS.

Filices.

1. *Angiopteridium* cf. *infinitum* FEISM.
2. *Cladophlebis* SP.
3. *Chonetes* SP.
4. *Glossopteris*? SP.

Ginkgoaceæ.

5. *Phenicepis*? *Yunnan* S. SP.

Incertæ Sedis.

6. *Carpodites* *Yunnan* S. SP.

塘 省 南 雲
Tang-tung in Yun-nan-Shêng.

塘 塘 省 南 雲
Shui-tung-p'u in Yun-nan-Shêng.

Occurrence of identical or allied species in other countries.

II. JURASSIC PLANTS.

Equisetaceæ.

1. *Selaginella laevigata* HEDER.
2. *Phyllocladus* SP.

Filices.

3. *Todites Williamsoni* (BRONGS.)
4. *Cladophlebis* SP.
5. *Coniopsis laevigata* (BRONGS.)
6. *Cheilosia Kuchinoi* S. SP.
7. *Cheilosia* SP.

Cycadeaceæ.

8. *Podocarpus laevigatus* (L. et H.)
9. *Pterophyllum*? SP.
10. *Nezumi*? SP.
11. *Dioonites Brownii* (MANT.)

Ginkgoaceæ.

12. *Ginkgo foliolata* HEDER.
13. *Ginkgo tepida* HEDER.
14. *Ginkgo* SP.
15. *Baiera gracilis* BESSE.
16. *Phenicepis laevigata* HEDER.
17. *Czekanowskia Manchourensis* (L. et H.)

Coniferae.

18. *Taxus manchourensis* S. SP.

Incertæ Sedis.

19. *Anthedon chinensis* S. SP.
20. *Carpodites globularis* S. SP.

III. CRETACEOUS PLANTS.

Filices.

1. *Coniopsis nitida* S. SP.
2. *Cladophlebis* SP.

Cycadeaceæ.

3. *Glossosaurus Holboellii* (SCHENK.) ...
4. *Glossosaurus arundinatus* S. SP.
5. *Podocarpus laevigatus* (L. et H.)

省 川 四
Sze-chuan-Si-fung

省 西 江
Chiang-tai-Shêng

中 山 鎮 有
Shan-Chih-tung

省 京 盛
Shêng-chung-Shêng

省 川 四
Sze-chuan-Si-fung

省 西 江
Chiang-tai-Shêng

中 山 鎮 有
Shan-Chih-tung

省 京 盛
Shêng-chung-Shêng

省 川 四
Sze-chuan-Si-fung

省 西 江
Chiang-tai-Shêng

中 山 鎮 有
Shan-Chih-tung

省 京 盛
Shêng-chung-Shêng

省 川 四
Sze-chuan-Si-fung

省 西 江
Chiang-tai-Shêng

中 山 鎮 有
Shan-Chih-tung

省 京 盛
Shêng-chung-Shêng

省 川 四
Sze-chuan-Si-fung

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省 川 四
Sze-chuan-Si-fung

省 西 江
Chiang-tai-Shêng

中 山 鎮 有
Shan-Chih-tung

省 京 盛
Shêng-chung-Shêng

The genus is widely distributed in the Rhotic of Europe.

Poland, Rhotic of Europe.
P. sibirica Hb. Siberia.

Siberia, Japan, other part of China, Europe.
Siberia, Japan, Korea, Europe.
C. Zenscheri Rac. Poland.
Do.

Siberia, Japan, other parts of China, Europe.
Japan, Korea? Wealden of Europe.

Siberia.
Siberia, Japan.
England.
Siberia, Norway.
Siberia, Japan, other parts of China, Europe.

P. Braunii Endl. Rhotic of Europe. P. imbric and conferta Feist. Jurassic of India.

Sphenopteris Cardai Schenk. Wealden of Germany.

Wealden beds of the Carpathians.
Rhotic to Cretaceous of several countries.

DESCRIPTION OF THE SPECIES.

I. TRIASSIC PLANTS.

A. T'ang-t'ang, Hsüan-wei-Chou.
Yün-nan-Shêng.¹⁾1. **ANGIOPTERIDIUM CFR. INFARCTUM** FEISTM.

Pl. I. Figs. 1-7.

Angiopteridium infarctum FEISTMANTEL, Flora of the Damuda and Panchet Divisions, p. 93, pl. XXXIVA, Figs. 4, 5, 5a.

We have several fragments of isolated pinnae of a fern which evidently belongs to the family of *Terniopteridae*. They are oblong-linear in shape slightly tapering both above and below. The apex is quite rounded, while the base narrows abruptly. The midrib is moderately strong, straight and evanescent. The secondary veins are fine, numerous, dense and parallel. They rise from the midrib at an angle of 40° - 45° , and then curving outward go obliquely to the margin of the pinna. Forking generally takes place close to the midrib, but further on, the veins remain mostly simple.

The greatest breadth attained by our specimens is 30 mm., but the length is not known. The density of the veins is about 4 to a millimeter.

The species, to which this Chinese form shows the greatest resemblance, is the one above named from the Triassic of

1) 雲南省宣威州倘塘

India which, however, has been founded on only two fragmentary pinnæ.

But so far as I can judge from the figures and descriptions of the Indian form, it seems to agree perfectly with the Chinese, both in the shape and size of the pinnæ, and also in the closeness of the veins. Still the specimens in both forms being imperfect, I deem it advisable at present not to assert their perfect identity.

2. CLADOPHLEBIS SP.

Pl. I. Figs. 8, 9.

The specimen shown in fig. 8 represents a fragment of a pinna of a fern which probably belongs to the collective genus of *Cladophlebis*.

The pinnules are finger-shaped, blunt at apex, close together, attached to the rachis by the whole base, mostly straight and slightly inclined forward. The midrib is distinct and evanescent: the secondary veins are not well preserved, but on careful examination, they seem to be twice forked.

Another specimen shown in fig. 9 has similar but smaller pinnules. The secondary veins have been totally defaced.

From the impossibility of determining the species of *Cladophlebis* from such meagre fragments, I leave them without any specific name.

3. CARPOLITHES YAMADAI N. SP.

Pl. I. Figs. 10, 11?

We have two fruits of an oval outline, with their apices, which may have been more or less pointed, broken off. One of

them (represented on the right hand side of fig. 10) measures 52 mm. long, 32 mm. broad and 10 mm. thick. They appear to have been sessile, with the place of attachment about 8 mm. broad.

The surface is nearly smooth, showing only longitudinal striations in its lower part.

These fruits have been found attached to each other by their lateral faces as if they were twins, so that the place of contact has been quite flattened. Their cross-section, as they now are, is elliptical, but this may possibly be a distortion by pressure, from a shape originally round.

It is quite singular that there is another, though much smaller, specimen (fig. 11) pressed almost flat, but also consisting of two pieces. If this specimen belongs to the same plant as the first, it is not at all impossible that the fruits were borne on the stem quite close to each other.

4. GLOSSOPTERIS? sp.

Pl. V. Fig. 2.

A fragment of the basal part of a frond. It shows a midrib, from which the lateral veins, though indistinct, are evidently divergent. It seems to belong to one of the species of *Glossopteris*, such as *G. indica* FEISTM. already described by ZEILLER (Flore Fossile des Gîtes de Charbon du Tonkin, pl. LVI, fig. 1) from Tai-p'in-ch'ang (太平場), a place also in Yünnan. It is much to be regretted that the only specimen from T'ang-t'ang is so imperfect as not to allow any accurate determination.

**B. Shui-t'ang-p'u, Hsüan-wei-Chou,
Yün-nan-Shêng.¹⁾**

1. ANGIOPTERIDIUM CFR. INFARCTUM FEISTM.

Pl. II. Fig. 2.

Two fragments of oblong-linear entire leaves. The one which has been figured measures about 16 mm. in breadth, pierced by a moderately strong, straight midrib. Although the secondary veins are mostly defaced, yet by a proper illumination, we can observe that they are very fine and dense, similar in their course to those of the above named species.

2. CLATHROPTERIS SP.

Pl. II. Fig. 3.

On a piece of stone, we see fragments of two broad laminae of a fern apparently partly overlapping each other. One of these laminae shows a distinct, but weak straight midrib which gives off at regular intervals straight secondary veins at angles of from 45° to 50°. They are mostly opposite or subopposite, but sometimes alternate. We have probably here to do with a species of *Clathropteris*, a genus widely distributed in the Rhætic formation of several countries.

1) 雲南省宣威州水塘舖

Shuitangpu is said to be an insignificant village, not quite 4 kilom. south of Ko-tu-ho (可渡河).

3. PHENICOPSIS (?) YAMADAI *n. sp.*

Pl. II, Fig. 1.

Leaves sessile, elongate wedge-shaped, always split into two more or less unequal lobes near the base. Lobes straight with sides subparallel, pierced with fine straight, dense, parallel veins.

Heer established the genus *Phenicopsis* (Beitr. zur Juraflora Ostsib. u. d. Amurl., p. 49) for long, linear, simple and undivided leaves attached to the stem in a bundle, and provided with dense parallel veins, while he brought similar leaves which repeatedly fork and possess rarer veins under the genus *Baiera* (l. c., p. 51). A fine specimen above figured from Yünnan has the general appearance of *Phenicopsis* on the one hand and the forked nature of the leaves of *Baiera* on the other. Should the apices of the leaves, which are all broken off in our specimens, prove to be broad, the plant would assume an appearance somewhat like *Rhipidopsis* SCHMALHAUSEN (Beitr. zur Juraflora Russlands, pl. VI and VIII) and need be treated as a new genus.

The breadth of the lobes measures over a centimeter at a place 6 centimeters from the base. But I presume they become still broader above. The veins are mostly simple, but near the base they seem to fork several times. Their number ranges between 20 and 30 in the broadest part of the lobes.

II. JURASSIC PLANTS.

A. Ch'ing-kang-lin, P'êng-Hsien, Ssu-ch'uang-Shêng.¹⁾

1. TODITES WILLIAMSONI (BRONGN.).

Pl. III.

Todites Williamsoni SEWARD, The Jurassic Flora-Yorkshire coast, part, I, p. 87, pl. XIV, figs. 2, 5, 7, XV, 1-3, XXI, 6.

Asplenium whitbyense SCHENK, Richthofen's China, vol. IV, p. 246, pl. XLVI, figs. 5-7, XLVII, 3-5, XLVIII, 1-4, p. 253, pl. LI, figs. 1-3. Fossile Pflanzen in Wissensch. Ergebn. d. Reise d. Grafen Bela Szécheny in Ostasien, p. 310, pl. I, figs. 1-2, III, 1-2. YOKOYAMA, Jurassic Plants from Kaga, Hida and Echizen, p. 31, pl. III, fig. 3, X, 1, 2.

This fern which had borne the names of *Cladophlebis whitbyensis*, *Asplenium whitbyense*, *Alethopteris whitbyensis* etc. was some years ago pointed out by SEWARD, as being closely related to the recent genus *Todea* in the nature of its fructification.

Our specimens are tolerably well preserved in two good-sized slabs of stone, the whole surface of which is covered with the pinnae of this fern which, however, are all sterile. The pinnules agree with those of the English specimens as described by SEWARD which, in spite of great variations in shape in different parts of a frond invariably have the acute apex and twice forked lateral veins.

This species occurs in several places in China, as will be seen further on.

2. PODOZAMITES LANCEOLATUS (LIND. ET HUTT.).

Pl. II. Figs. 5, 6.

P. dozamites lanceolatus SCHENK, Jurassische Pflanzen in Richthofen's China, vol. IV, p. 248, pl. XLIX, figs. 4, 5, p. 251, L, 1-6, p. 255, LI, 3, LI, 8,

1) 四川省彭縣青崗林

p. 258 LI, 7, p. 261, LIV, 2c. Fossile Pflanzen in Wissens. Ergebn. d. Reise d. Grafen Bela Szécheny in Ostasien, p. 317, pl. II, figs. 8^a, 9^b, III, 9, p. 320, II, 5. KRASSER, Die von W. A. Obrutschew in China u. Centralasien 1893-1894 gesam. fossilen Pflanzen, p. 146 pl. IV, fig. 1. YABE, Mesozoic Plants from Korea, p. IV, figs. 1-5. YOKOYAMA, Jurassic Plants from Kaga, Hida and Echizen, pl. 45, pl. IV, figs. 1a, 1c, 2, 3a, 4ab, V, VI, 1, VII, 8b, XII, 18. FEISTMANTEL, Fossil Flora of the Jabalpur Group, p. 11, pl. III, figs. 4-7, IV, 1-10.

The specimen represented in fig. 6 shows leaflets as they were attached to the rachis. Most of these leaflets have about 15 veins, and in shape correspond to what Heer distinguished as variety *minor*, although some are a little too broad for that. The one on the left side and in the lower corner is a long oval in shape. These facts show how variable the leaflets of this plant are, even on the same rachis.

The specimens shown in fig. 5 are isolated leaflets. The one in the right lower corner is the smallest of all the leaflets found at Ch'ing-kang-lin. It has an acute apex with about 15 veins, and resembles the oval one above alluded to.

The subdivision of this species into many varieties according to the form of the leaflets, as has been done by HEER, is, I believe, not tenable, as already pointed out by SEWARD.

3. ANTHOLITES CHINENSIS N. SP.

Pl. II. Fig. 4.

The only specimen we possess consists of a fragments of a stem, 2 mm. in breadth, and almost entirely changed into coal, on both sides of which are attached somewhat oval or sometimes, slightly quadrate bodies about 5 mm. long and 3 mm. broad, forming quite a close row. It probably represents an inflorescence of some coniferous or *Ginkgo*-like tree or, indeed, of a male catkin, the oval bodies being pollen-sacs.

**B. Ta-shih-ku, Chung-ching-Fu (Pa-Hsien),
Ssu-ch'uang-Shêng.¹⁾**

1. TODITES WILLIAMSONI (BRONGN.).

Pl. V, Fig. 1a.

We have several pinnæ of a fern well preserved and undoubtedly belonging to the species above named. The pinnales are often 20 mm. long, acute and furnished with twice forking secondary veins.

2. CARPOLITHES GLOBULARIS N. SP.

Pl. V. Fig. 1b.

On a stone with *Todites Williamsoni* are scattered many small spherical bodies mostly about 5 mm. in diameter, but sometimes a little larger. One of them is provided with a petiole 3 mm. long. They are probably seeds belonging to a plant of the family *Ginkgoaceæ*.

The seeds taken by SAPORTA as belonging to *Baiera Muensteriana Presl* (Paléontologie Française, Plantes Jurassiques, vol. III, pl. XXIX, fig. 3) show some resemblance to the present species, but they are more oblong in shape.

What has been figured by HEER (Beitr. z. Juraflora, pl. VIII, fig. 12) as belonging to *Baiera longifolia* HEER are a little larger than ours.

**C. Lung-wang-tung, Chiang-pei-Ting,
Ssu-ch'uang-Shêng.²⁾**

From this locality we possess two indeterminable fragments of Equisetum-like stems which, however, apparently belong to

1) 四川省重慶府(巴縣)大石鼓

2) 四川省江北廳龍王洞

two different forms. The one (fig. 3, Pl. X) has the longitudinal grooves nearly 2 mm. apart, while the other (fig. 2, pl. X) has them much closer together, so that it looks somewhat like *Schizoneura horensis* HISINGER hereafter to be described from Nien-tzu-kou near Sai-ma-chi in Shêng-ching.

**D. Sha-shih-chieh, An-yüan, P'ing-hsiang-Hsien,
Chiang-hsi-Shêng.¹⁾**

1. PCDOZAMITES LANCEOLATUS (LANDL. ET HUTT.).

Pl. IV. Fig. 3.

Two fragments of leaflets giving their basal portion. Their shape and venation undoubtedly point to the well known species above named.

2. PHÆNICOPSIS LATIOR HEER.

Pl. IV. Fig. 4.

Phœnicopsis latior HEER, Beitr. zur Jurafloora Ostib. u. d. Amurl., p. 113, pl. XXXI, figs. 1-6, XXIV, 1c. Ueber die Pflanzenversteinerungen von Andø in Norwegen, p. 13, pl. L, figs. 5-10.

Fragments of isolated leaves which measure up to 10 mm. in breadth, with 23 or 24 close veins. An interstitial vein is sometimes observable. The way in which the leaves narrow toward their base admits no doubt about their being *Phœnicopsis*, and indeed, *P. latior* HEER. That they do not belong to *P. speciosa* HEER is shown by their having more numerous veins and a more abruptly narrowed base. Small fragments only 6 or 7 mm. broad still possess 23 veins.

1) 江西省萍鄉縣安源沙市界

**E. San-chia-chung, An-yüan, P'ing-hsiang-Hsien,
Chiang-hsi-Shêng.¹⁾**

1. PODOZAMITES LANCEOLATUS (LINDL. ET HUTT.).

Pl. IV. Fig. 2.

We have only a single fragment of the basal portion of a leaflet, but it undoubtedly belongs to the above named species.

**F. Kao-kang, P'ing-hsiang-Hsien,
Chiang-hsi-Shêng.²⁾**

1. PODOZAMITES LANCEOLATUS (LINDL. ET HUTT.).

Pl. IV. Fig. 1.

On a slab of a dark coloured shale, there are several isolated, more or less fragmentary leaflets which also belong to the same species as that of San-chia-chung.

**G. Ch'ung-chia-fang, I-ch'un-Hsien,
Chiang-hsi-Shêng.³⁾**

1. PODOZAMITES LANCEOLATUS (LINDL. ET HUTT.).

Pl. IV. Figs. 5, 6.

From this place came three fragments which we have identified with the species found in the above two places.

**H. Ssu-lu-p'u, Hsing-an Hsien,
Chiang-hsi-shêng.⁴⁾**

1. PTEROPHYLLUM? sp.

Pl. IV. Fig. 9.

A fragment of a leaf with close segments, whose apices are all broken off. They are slightly inclined forward, about 3 mm.

1) 江西省萍鄉縣安源三夾冲

2) 江西省萍鄉縣高坑

3) 江西省宜春縣鐘家坊

4) 江西省興安縣司路舖

broad, and furnished with many parallel veins which are, however, very indistinct. In appearance, the specimen is not unlike that of *Pterophyllum Nathorsti* SCHENK (RICHHOFEX's China, pl. XIII, figs. 5, 7), but it might belong equally as well to the genus *Nilssonia*.

2. NILSSONIA? sp.

Pl. IV. Figs. 10, 11.

We possess two fragments, both of which have been figured. The one (fig. 10) represents an apical portion and seems not to be segmented. The other (fig. 11) shows two segments 6 to 7 mm. long and about 6 mm. broad, pierced with fine parallel veins numbering about 10.

I. Liao-chia-shan, Fêng-ch'êng-Hsien. Chiang-hsi-Shêng.¹⁾

1. CLADOPHLEBIS sp.

Pl. IV. Figs. 7, 8.

Two fragmentary pinnæ of a *Cladophlebis* with closely set finger-like pinnules slightly inclined forward and furnished with furcate lateral veins. The forking is commonly single but in some cases double, especially in veins on the anterior side of the midrib.

The specimens look like some of the figures given by SCHENK as *Asplenium argutulum* HFER (e. g. figs. 2 and 3, pl. XLVI.

¹⁾ 江西省豐城縣廖家山

RICHTHOFEN'S China l. c.), or by HEER as *A. whitbyense* (fig. 3, pl. LIII, Beiträge l. c.). But it is not possible now to determine them with any degree of accuracy.

**J. Fang-t'u, Wei-Hsien,
Shan-tung-Shêng.¹⁾**

1. CONIOPTERIS HYMENOPHYLLOIDES (BRONGN.).

Pl. VI. Fig. 3.

Coniopteris hymenophylloides SEWARD. The Jurassic Flora—The Yorkshire Coast, p. 99, pl. XVI, fig. 4-6, XVII, 3, 6-8, XX, 1, 2, XXI, 1-4.

Sphenopteris hymenophylloides BRONGNIART. Histoire Végétaux Fossiles, p. 189, pl. LVI, fig. 4.

Thyrsopteris Murrayana HEER. Beitr. zur Jurafloa Ostsib., 1876, p. 30, pl. II, fig. 4, II, 1-4, VIII, 11 b. Yokoyama Jurassic Plants from Kaga, Hida and Echizen, p. 22, pl. XII, fig. 5.

Thyrsopteris Maakiana HEER, Beitr. z. Jurafloa, 1876, p. 31, pl. I, fig. 1-3, II, 5, 6.

Dicksonia nephrocarpa YOKOYAMA, loc. cit., p. 25, pl. I, fig. 1.

For further synonyms see SEWARD already cited.

SEWARD in the work before cited united many ferns theretofore known under different names with the British species which was first described by BRONGNIART under the name of *Sphenopteris hymenophylloides*. The reason why this plant received so many different denominations is undoubtedly due to the great variability in form of the pinnules, as has been proved by Seward and also to the fact that the fertile pinnules had been treated as belonging to a different fern.

Some fragments of pinnae of a fern brought from the coal-mine of Fang-t'u, in spite of their rather imperfect preservation,

1) 山東省濰縣坊子炭坑

I consider to belong to the British species above referred to. Our figured specimen shows a very great resemblance to fig. 2, pl. XX of SEWARD. Better specimens of this species were found at Lao-tung-ts'ang in Chih-li as will be seen further on.

MR. YABE is probably right in referring specimens found by him in Korea to this species, (Mesozoic Plants from Korea, pl. II, fig. 8, III, 8) imperfect as they are.

2. **TODITES WILLIAMSONI** (BRONGN.).

Pl. VI. Fig. 4.

Todites Williamsoni SEWARD, The Jurassic Flora, p. 87, pl. XIV fig. 2, 5, 7, XV, 1-3, XXI, 6.

On a large slab of stone is a splendid frond of a fern which by the characteristic shape and venation of its pinnules, indubitably belongs to the well known form above cited, and which, not only has been already described from Ch'ing-kang-lin in Ssu-ch'uang, but also occurs near Sai-ma-chi in Shêng-ching, as will be seen later on. Our figure represents only* a portion of the frond found.

3. **CTENIS** sp.

Pl. VI. Fig. 1 a

We possess only a portion of a pinna which shows alternate, elongated pinnules which are dilated at base and decurrent on the rachis. The entire length of the pinnules is not known, as we have only a small part of them preserved. Their breadth

near the base measures 25 to 28 millimeters. The veins, which are slightly divergent and therefore run more or less to the margin, dichotomize here and there and again anastomose, thus forming a network of meshes much elongated transversely. The number of veins is about 12 in the space of a centimeter.

In general aspect, this fern resembles *Ctenis Zeuschneri* RACIBORSKI (Flora Kopalna, p. 61, pl. XVI) from the Jurassic of Poland, but the latter possesses much closer veins, there being 16 to 24 in the space of a centimeter. *Ctenis remotinervis* RACIBORSKI (ibid., p. 59, pl. XVIII, fig. 2), also from the same place, resembles the Chinese form in the number of the veins (8 to 12 in the space of a centimeter), but the nets seem to be much shorter.

4. **PODOZAMITES LANCEOLATUS** (LINDL.).

Pl. VI. Fig. 1 b, 2.

There are several isolated leaflets of this plant, some of which are very long and narrow. The one shown in the figure (1 b) has about 15 veins.

K. Lao-tung-ts'ang, Hsüan-hua-Fu,
Chih-li-Shêng.¹⁾

1. **CONIOPTERIS HYMENOPHYLLOIDES** (BRONGN.).

Pl. VII. Figs. 1-5.

Coniopteris hymenophylloides SEWARD, The Jurassic Flora, p. 99, pl. XVI, figs. 4-6, XVII, 3, 6-8, XX, 1, 2, XXI, 1-4.

The species which has been already described from Fang-t'u

1) 直隸省宣化府老東蒼(鷄鳴山の北)

in the province of Shan-tung is here represented by several well preserved specimens which however belong to sterile pinnae.

An example represented in fig. 2 belongs to the apical portion of a primary pinna. The secondary pinnae are alternate, elongated, springing from the rachis at a wide angle, and separated from one another by an interspace which is generally narrower than the breadth of the pinnae. The pinnules are more or less rhomboidal in general outline and possess a few rounded lobes, while the lowest of them, especially the one on the posterior side, show lobes which are spreading and irregular, a character already noticed by SEWARD in his British specimens.

Fig. 5 represents a pinna with more lacinated pinnules, while in the specimen shown in fig. 4, the pinnules are small and entire, showing only here and there slight traces of lobation.

As already stated, the variability in the form of the pinnules of this species has been amply proved by SEWARD in the work above cited.

2. GINKGO FLABELLATA HEER.

Pl. VII. Figs. 6-9.

Ginkgo flabellata HEER. Beitr. z. Jurafloora Ostsib. u. d. Amurl., 1876, p. 60, pl. VII, fig. 19, XIII, 3, 4. Nachtrag, p. 16, pl. IV, fig. 7a.

HEER's description of this species is as follows ;

"Leaves small, kidney-shaped, deeply lobed, lobes 8 to 14, oblong, obtuse at apex ; veins longitudinal, 3 to 5 in number ; petiole slender, elongated."

We have several fragments of leaves of a *Ginkgo* which we identify with the above named species of HEER, although some look much like those also described by HEER as *Ginkgo pusilla*.

At all events, even granting that these two species are distinct, it would be impossible to distinguish them, if the specimens existed only in imperfect fragments, so alike are they in appearance.

An example represented in fig. 8 shows four lobes, one of which is again split into two, each of which measures about 3 mm. in breadth. The three others are all simple and possess about the same breadth as the other two. The length in the one at the extreme right, in which the apex is well preserved, is about 15 mm. The others which all lack the apex seem to be a little longer. The veins are indistinct, but appear to number 4 or 5.

A fragment represented in fig. 7 shows only two lobes, one of which is again split into two by a shallow incision. The lobes are all apically rounded, and measure not quite 3 mm. in breadth. Their length is not known as their basal portion is broken off. The veins are again indistinct.

Fig. 6 represents another isolated lobe partly split into two blunt loblets which are about 3 mm. in breadth. Its shape is slender in comparison with those of the typical form.

**L. Nien-tsu-kou, Sai-ma-chi,
Shêng-ching-Shêng.¹⁾**

1. TODITES WILLIAMSONI (BRONX).

Pl. VIII. Fig. 1.

There are several splendid specimens of this world-wide fern which I have already described from Ssu-ch'uang. They all belong to the sterile pinnae which, however, show all the characteristics of the species.

1) 盛京省賽馬集礦子溝

2. CTENIS KANEHARAI N. SP.

Pl. IX. Figs. 1, 1a.

The frond is pinnate. The pinnules or segments are alternate, elongated, somewhat inclined forward, slightly overlapping, mostly parallel-sided, but slightly narrowed at base, and attached laterally to a straight rachis which is longitudinally striated. The length of the pinnules is not known, as they are not wholly preserved, but the breadth in one of them is 35 mm. which diminishes to 20 mm. at base. The stem or rachis is straight and measures 10 mm. in breadth. The veins are numerous, parallel, about 10-12 in the space of a centimeter measured across the segment, often dichotomizing and also uniting so as to form an elongated mesh.

The only specimen which we possess is incomplete as may be seen from the figure, but the above given characters sufficiently show that the plants belong to a form hitherto undescribed. In the size of the segments and the fineness of the venation, it resembles *Ctenis Zeuschneri* RACIBORSKI (Flora kopalna ogniotrwalyk glinek krakowskich, czesc 1, Archegoniatae, p. 60, pl. XVI) from the Polish Jurassic, but in the former the basal portion of the segments is much more abruptly narrowed than in the latter.

3. SCHIZONEURA HÆRENSIS (HISINGER).

Pl. VII. Fig. 10.

Schizoneura hærensis RACIBORSKI, Flora kopalna ogniotrwalyk glinek krakowskich, czesc 1. *Archegoniata*, p. 95, pl. XXVI, fig. 7, XXVII 28-31, 37-43. NATHORST, Floran vid Höganäs och Helsingborg, p. 9, 10, Höganäs äldre, pl. I, figs. 1-4, Helsingborg, pl. I, fig. 5. MÖLLER, Bidrag till Bornholm's fossila flora, *Pteridophyta*, p. 60, pl. VI, fig. 19.

Calamites Guembeli SCHENK, Die fossile Flora der Grenzsichten d. Keupers u. Lias Frankens, p. 10, pl. I, figs. 8-10.

A single specimen of a fragment of an equisetoid stem 25 mm. broad, and 170 mm. long, of which the lower 90 mm. is a cast. There are two nodes, one near the upper end of the fragment, and the other about 70 mm. from its lower end, the internode between being nearly 90 mm. in length. The surface of the stem shows longitudinal ridges and grooves, the former about half a millimeter broad and the latter much narrowed. The surface of the ridges is finely striated in the longitudinal direction.

I believe this plant is to be identified with the well known species widely distributed in the Rhætic of Europe, and according to RACIBORSKI, also occurring in the Jurassic of Poland.

4. **BAIERA GRACILIS** BUNBURY.

Pl. IX. Fig. 2a.

Baiera gracilis SEWARD, The Jurassic Flora-Yorkshire Coast, part I, p. 263, pl. IX, figs. 3, 5.

Baiera? gracilis BUNBURY, Quart. Journ. Geol. Soc., vol. VII, p. 182, pl. XII, fig. 3.

The specimen which I designate by the above name is a leaf consisting of several lobes which again divide into two long narrow ones. These are more or less parallel-sided, bluntly pointed, 3-5 mm. broad, pierced with 3 or 4 longitudinal veins, between which several interstitial ones are also observable. The lower part of the leaf is not preserved, but that it is a fan-shaped one is quite evident. I believe it is to be identified with the species above named, described long ago from Scarborough in England.

5. GINKGO LEPIDA HEER.

Pl. IX. Fig. 2b.

Ginkgo lepidus HEER, Beitr. z. Jurafloora Ostsib. u. d. Amurl., p. 62, pl. VII, fig. 7, pl. XII. Nachtrag, p. 17, pl. IV, figs. 7b, 9-12, pl. V, figs. 1a, 2, 3a, 4.

Ginkgo cf. lepidus YOKOYAMA, Jurassic Plants from Kaga, Hida and Echizen, p. 60, pl. XIV, fig. 10.

On the same piece of stone as the above species, there is another fan-shaped leaf which has a petiole 2 mm. broad and 20 mm. long. This petiole above splits twice into two, each branch bearing three to five narrow lobes which are shorter in comparison with the breadth than in the preceding species. The length of the lobes varies, but the breadth is commonly about 3 to 5 mm. Their apices are bluntly pointed. Veins are few, about five in number in the broadest part of the lobes.

According to HEER, this species is distinguished from *Ginkgo sibirica* HR., an allied one, by the leaf splitting into more numerous lobes which are narrower and pointed.

6. CZEKANOWSKIA MURRAYANA (LINDL. ET HUTT.).

Pl. X. Fig. 1.

Czekanowskia Murrayana SEWARD, The Jurassic Flora I, p. 279, text-figs. 48-50.

Solenites Murrayana LINDLEY AND HUTTON, Fossil Flora of Great Britain, vol. III, pl. 121.

Czekanowskia rigida HEER, Beitr. zur Jurafloora I. c., pl. V and VI. (pars). SCHENK in Richthofen's China, vol. IV, p. 251 pl. L, fig. 7.

A piece of stone from Sai-ma-chi is covered with several tufts of long narrow leaves, one to two millimeters in breadth,

and occasionally dichotomizing. The veins are entirely obliterated. The length of the leaves must have been more than 10 cm., but there is none that is preserved up to the apex. Looking at the figure, some of the leaves seem to be tolerably broad: but this is only an appearance due to their partial overlapping.

Although the breadth of the leaves is a little greater than in most of the specimens hitherto found in other countries, I believe, the plant belongs to the same species.

7. **PALYSSIA MANCHURICA** N. SP.

Pl. VIII. Fig. 2, 2a.

A single specimen of a branch of a *Palyssia* shows subopposite branchlets, with leaves linear, broadest at a point about one-third of the distance from the base, expanding, acuminate, recurved, spirally disposed, on a cushion decurrent and sessile. The midrib is strong, elevated as a ridge on the back side of the leaf.

The species already described which can be compared with this one are three, viz. *Palyssia Brauni* ENDL., *P. indica* FEISTM. and *P. conferta* FEISTM. The first occurs in the Rhaetic of Europe and has been figured by SCHENK, SCHIMPER and others, and when compared with the Chinese form, shows leaves which are decidedly longer. The second which occurs in the Rajmahal (Liassic) and Cutch (Lower Oolite) Series of India has leaves which besides being larger, are obtuse at apex. The third, also found in the Cutch Series, shows leaves which, though more or less acute, are more parallel-sided and not so recurved as in those of the Chinese form.

**M. Sha-ho-tzu, Ch'ang-tu,
Shêng-ching-Shêng.¹⁾**

1. DIOONITES BRONGNIARTI (MANT.).

Pl. XI. Figs. 1, 2.

Dioonites Brongniarti SEWARD, The Wealden Flora, p. 47.

Dioonites Kotai YOKOYAMA, Jurassic Plants, p. 44, pl. VII, fig. 1abc, XIV, 14.

This is the only fossil brought from the Sha-ho-tzu coal-mine. It consists of several fragments, some belonging to the apical portion (fig. 2) of a leaf, and some to the middle portion (fig. 1) of the same. The segments are close together, long, narrow, parallel-sided, either straight or very slightly curved forward, attached to the upper surface of the rachis by the whole base and more or less inclined forward, especially near the apex of the leaf. The apices of the segments are mostly broken off, but judging from their form, they seem to have been bluntly pointed. The most of the segments are about 3 mm. broad, pierced by 6-7 fine, equal, parallel veins.

I formerly described a species of *Dioonites* found in the Jurassic of Kaga and Echizen under the name of *D. Kotai* which SEWARD considers as probably identical with *D. Brongniarti*, an opinion to which I now quite agree.

**N. Ta-t'ai-shan, Ch'üan-yen-kou,
Shêng-ching-Shêng.²⁾**

1. PODOZAMITES LANCEOLATUS (LINDL. ET HUTT.).

Pl. XI. Fig. 3.

Seven fragments of leaflets of *Podozamites lanceolatus* which

1) 盛京省昌圖沙河子

2) 盛京省泉眼溝大台山 (12 kilom. south-west of T'ieh-ling).

are blunt at apex are contained in one piece of stone. The veins are numerous, being up to 20 in number and mostly provided with a finer interstitial vein. In shape they correspond to what HEER once called the variety *Eichwaldi*.

2. GINKGO sp.

Pl. XI. Figs. 4-7.

We have several specimens of leaves of a *Ginkgo* all of which lack their apical portions. Their general shape however reminds us of those of *Ginkgo lepida* (HEER Beitr. z. Juraflora Ost-sib. 1876, pl. XII) and *Ginkgo sibirica* (ibid. pl. XI), although fig. 7 is also not unlike that of *Ginkgo concinna* HEER (ibid. pl. XIII, fig. 7).

0. Pao-êrh-shan, Shêng-ching-Shêng.¹⁾

1. PHYLLOTHECA sp.

Pl. XI. Fig. 8.

Numerous fragments of roots of an equisetaceous plant, 1-3 mm. in breadth and with slender fibres rising from them, look very much like those figured by HEER from Siberia, as probably belonging to his *Phyllothecca sibirica* (Beitr. z. Juraflora Ost-sib. u. d. Amurl., 1876, p. 43, pl. IV, fig. 7).

1) 盛京省抱兒山 (30 kilom. south-east of Tieling).

III. CRETACEOUS PLANTS.

A. Shi-huan-tzu, Chao-hua-Hsien, Su-ch'uang-Shêng.¹⁾

1. CONIOPTERIS NITIDULA N. SP.

Pl. XII. Fig. 4, 4a.

Fronde tripinnate. Primary pinnae elongated. Secondary pinnae also elongated, bluntly pointed, attached to the rachis at a very wide angle, close together and often touching. Pinnules short, blunt, inclined forward, very close together, united at base so as to appear like mere lobes, indistinctly and coarsely crenate. Veins few, the midvein which is fine and goes off at an acute angle from the rachis usually forks twice, so that the pinnules become three-veined.

Our only specimen, shown in the figure, represents two primary pinnae side by side, but separated from each other by a short interspace. The secondary pinnae which measure about 10 mm. in length and about 2 mm. in breadth are generally given off at right angles to the rachis and possess 6 or 7 pinnules besides the terminal one.

This plant shows a distant resemblance to *Coniopteris hymenophylloides* BRONG. already described from Lao-tung-ts'ang in the province of Chih-li, but the shape of the pinnules in the two is quite different.

A closer relationship is shown by *Sphenopteris Cordai* SCHENK (Foss. Flora d. norddeutsch. Wealdenform., pl. VI, fig. 1.) which, however, seems to have pinnules a little larger

1) 四川省昭化縣石鏡子

and more distinctly crenate. Of the generic denomination, I am not quite certain.

2. GLOSSOZAMITES HOHENEGGERI (SCHENK.).

Pl. XII. Fig. 1, 1a.

Podozamites Hoheneggeri SCHENK, Die fossilen Pflanzen der Wernsdorfer Schichten in den Nordkarpathen, p. 9, pl. II, figs. 3-6.

A cycad, hitherto known only from the Urgonian beds of Wernsdorf in the Northern Carpathians, is represented in China by the fine specimen here figured and one other less perfect. The figured specimen represents a part of a leaf probably belonging to its lower portion. The leaf is pinnate with segments inserted upon the rachis, but as the specimen shows the back side of the leaf, they appear as if attached to the lateral sides of the rachis. Segments are linear, obtuse, rather abruptly narrowed at base, sessile, straight, varying in length, being longest in the middle portion of the leaf, sub-opposite or alternate, mostly set at right angles to the rachis, only slightly inclined forward in the anterior portion, separated from one another by an interval which varies but is generally less than the breadth of the segments; but in the anterior part they are closer and almost touch. The rachis is slender, straight and longitudinally grooved. The veins in our specimens are not well preserved, but on careful examination they are seen to be fine, divergent and dichotomous, just as represented in SCHENK's figure.

The length attained by the longest segments is not exactly known, for all of them have their apices broken off. But this much is certain that they are more than 30 mm. long, with a breadth of about 5 mm.

3. PODOZAMITES LANCEOLATUS (LIND. ET HUTT.).

Pl. XII. Fig. 3.

A part of a stem with leaves attached to it which possess about 16 veins and corresponding in shape to the variety *genuina* of HEER.

B. Sha-chi-miao, Ho-Chou,**Ssu-ch'uang-Shêng.¹⁾****1. CLADOPHLEBIS** SP.

Pl. XII. Fig. 2.

A faint impression of a fragment of a pinna of a fern probably belonging to the genus *Cladophlebis*. The pinnules are close together, falcate, pointed, with secondary veins once forked. It is not unlike a specimen figured by SCHENK as *Alethopteris Albertsii* SCHIMP. from the Wealden of Germany (Foss. Flora d. nordwestdeutschen Wealdenform., pl. VI. fig. 4.)

2. GLOSSOZAMITES HOHENEGGERI (SCHENK.).

Pl. XII. Figs. 5a, 6?

Fig. 5a is an isolated segment lacking the apex. It is 20 mm. long with the broadest part about 5 mm., and lying a little anterior to its middle portion. From this broadest part, it gradually narrows to the base where the breadth is only 2 mm. The veins are fine, but distinct, divergent and dichoto-

1) 四川省合州沙溪廟

mous, numbering about 15 in the broadest part. Between these veins, there are longitudinal striations.

Another segment represented in fig. 6 is comparatively a broad one, attaining a breadth of 6,5 mm., while its length is 35 mm. The veins are quite of the *Glossozamites* type, so that it probably belongs to the same species as the other specimen.

3. GLOSSOZAMITES ACUMINATUS N. SP.

Pl. XII. Figs. 5b, 7.

What I call by the above name are long, lanceolate segments, broadest near the base and gradually tapering above to an acuminate apex. A specimen shown in fig. 5b attains the breadth of 10 mm., while its length, if it had the apex preserved, would measure more than 70 mm. The base measures about 7 mm. in breadth and has no stalk. The veins are distinct, divergent and dichotomous, quite in the *Glossozamites* style. They number about 20 in the broadest part. The interspaces are longitudinally striated as in the preceding species. Fig. 7 represents the apical portion of a segment, though the extreme apex is broken off.

In shape these segments are considerably different from those of *Glossozamites Hoheneggeri*. Therefore at present I prefer to treat them as belonging to a new species.

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MESOZOIC PLANTS FROM CHINA.

PLATE I.

Plate I.

Triassic Plants.

T'ang-t'ang (Yün-nan).

Figs. 1-7. *Angiopteridium* cf. *injunctum* FEISTM.

Fig. 1a. A part of the same enlarged to show the venation.

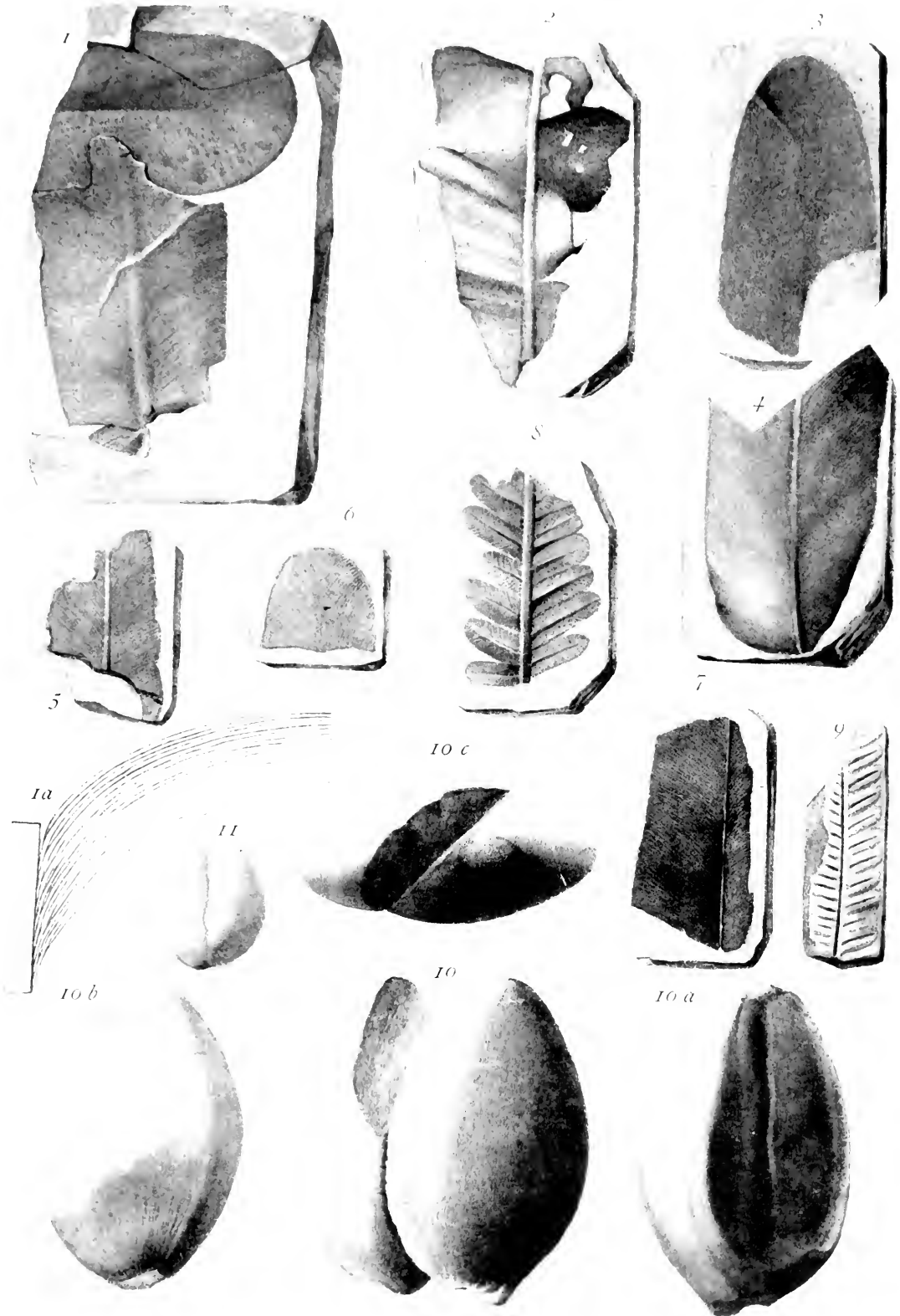
Figs. 8, 9. *Cladophlebis* sp.

Fig. 10, 11? *Carpolithes Yamadae* n. sp.

Fig. 10a. Do. showing the face of contact of one of the twin-fruits represented on the right hand side of fig. 10.

Fig. 10b. Do. showing the back-surface of one of the twin-fruits represented on the left-hand side of fig. 10.

Fig. 10c. Twin-fruits seen from below.



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MESOZOIC PLANTS FROM CHINA.

PLATE II.

Plate II.

Triassic Plants.

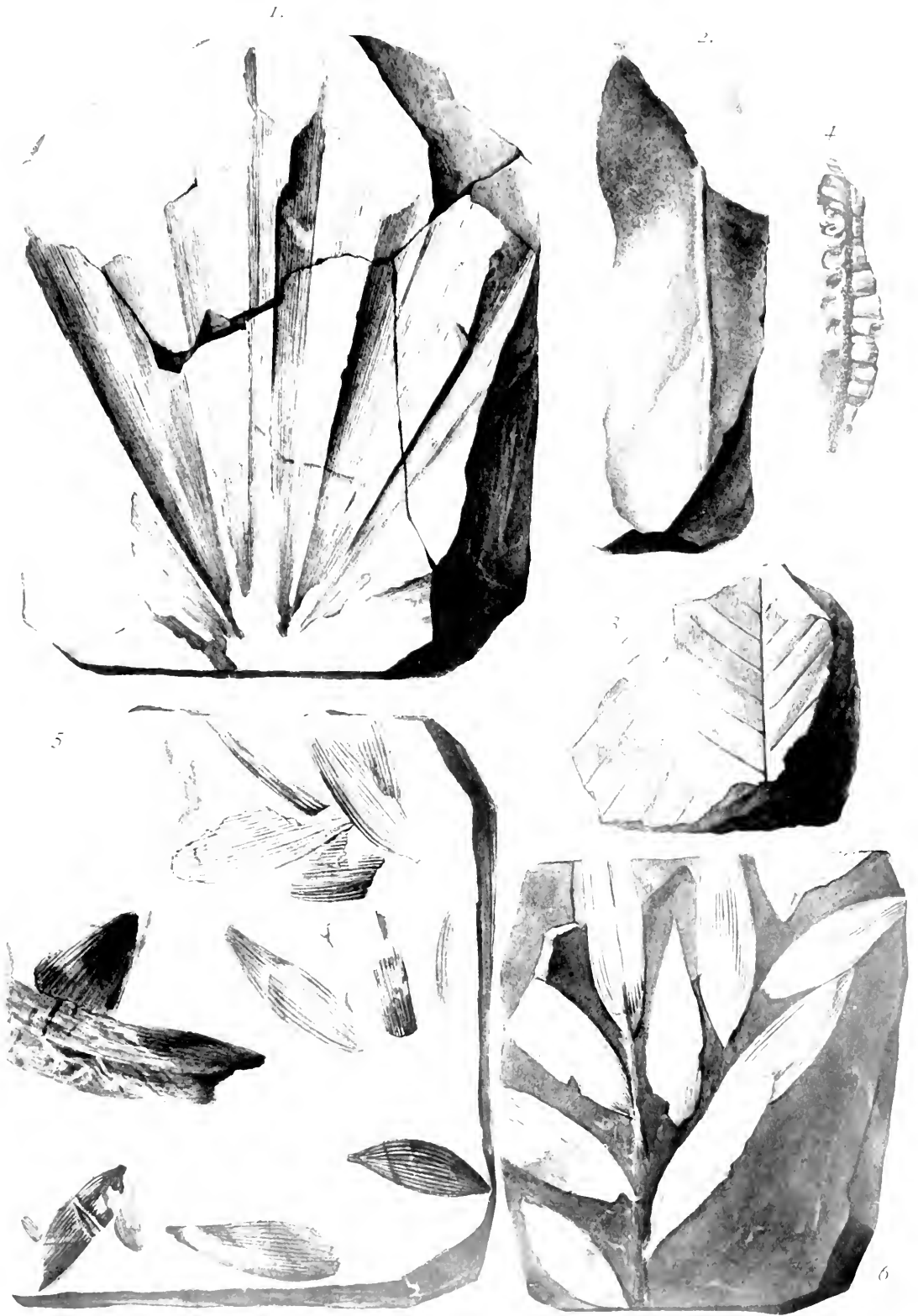
Shui-t'ang-p'u (Yün-nan).

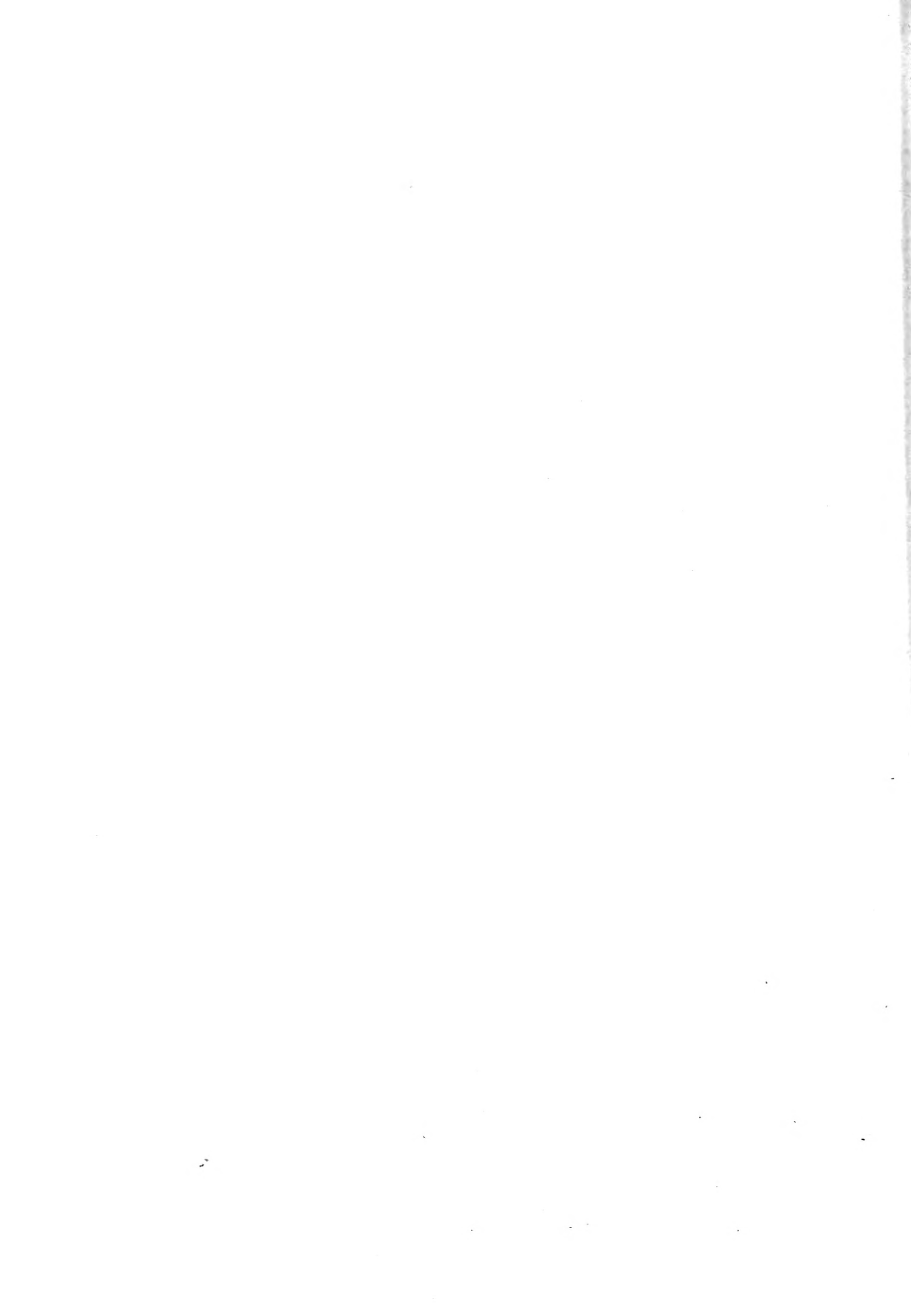
- Fig. 1. *Phœnicopsis* (?) *Yunadai* n. sp.
Fig. 2. *Angiopteridium* cf. *infarctum* FEISTM.
Fig. 3. *Clathropteris* sp.

Jurassic Plants.

Ch'ing-kang-lin (Ssu-ch'uang).

- Fig. 4. *Antholites chinensis* n. sp.
Figs. 5, 6. *Podoxamites lanceolatus* (LINDL. ET HUTT.).





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MESOZOIC PLANTS FROM CHINA.

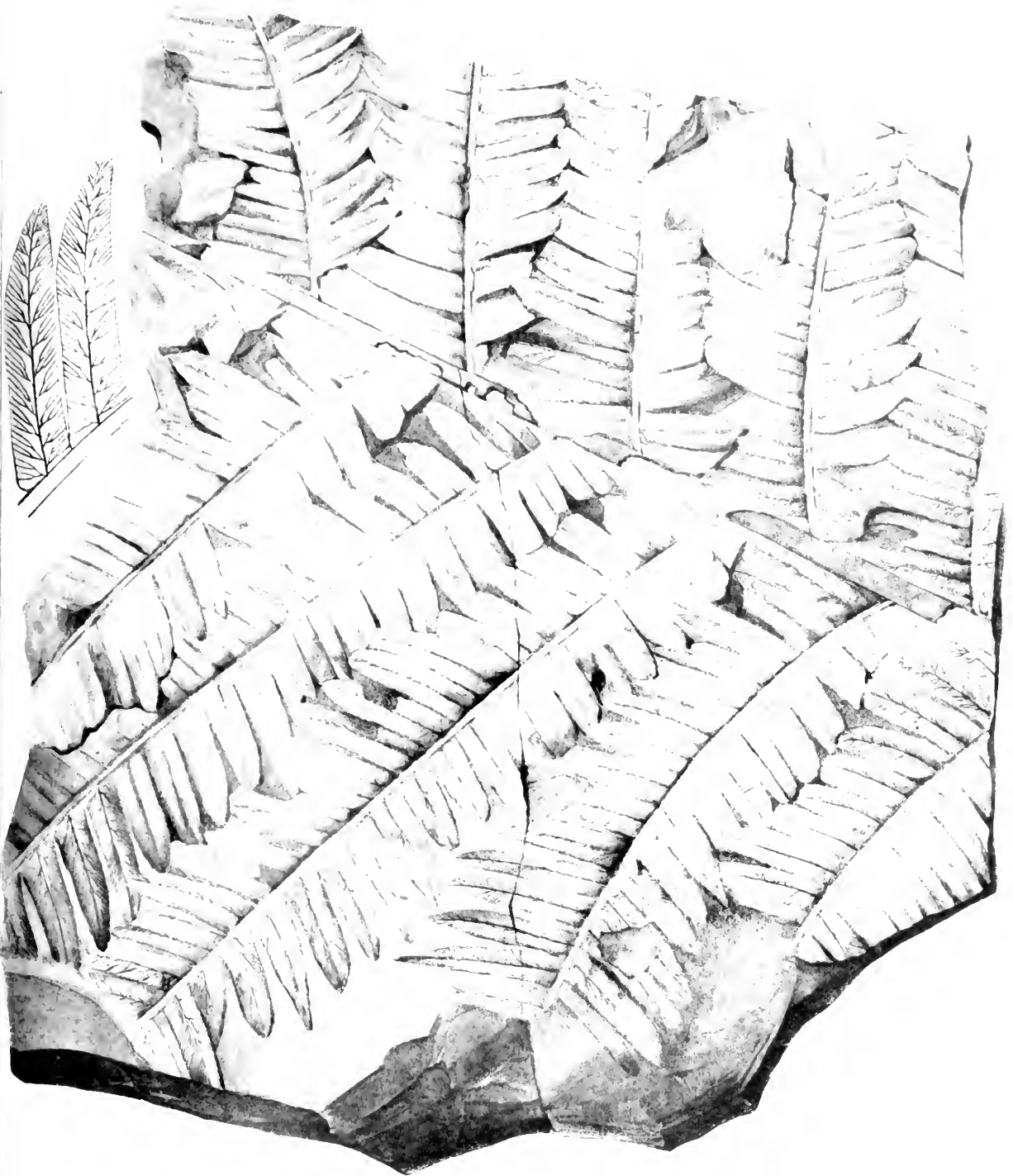
PLATE III.

Plate III.

Jurassic Plants.

Ch'ing-kang-lin (Ssu-ch'uang).

Fig. 1. *Todites Williamsoni* (BRONGN.), with two magnified pinnules on the left.





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MESOZOIC PLANTS FROM CHINA.

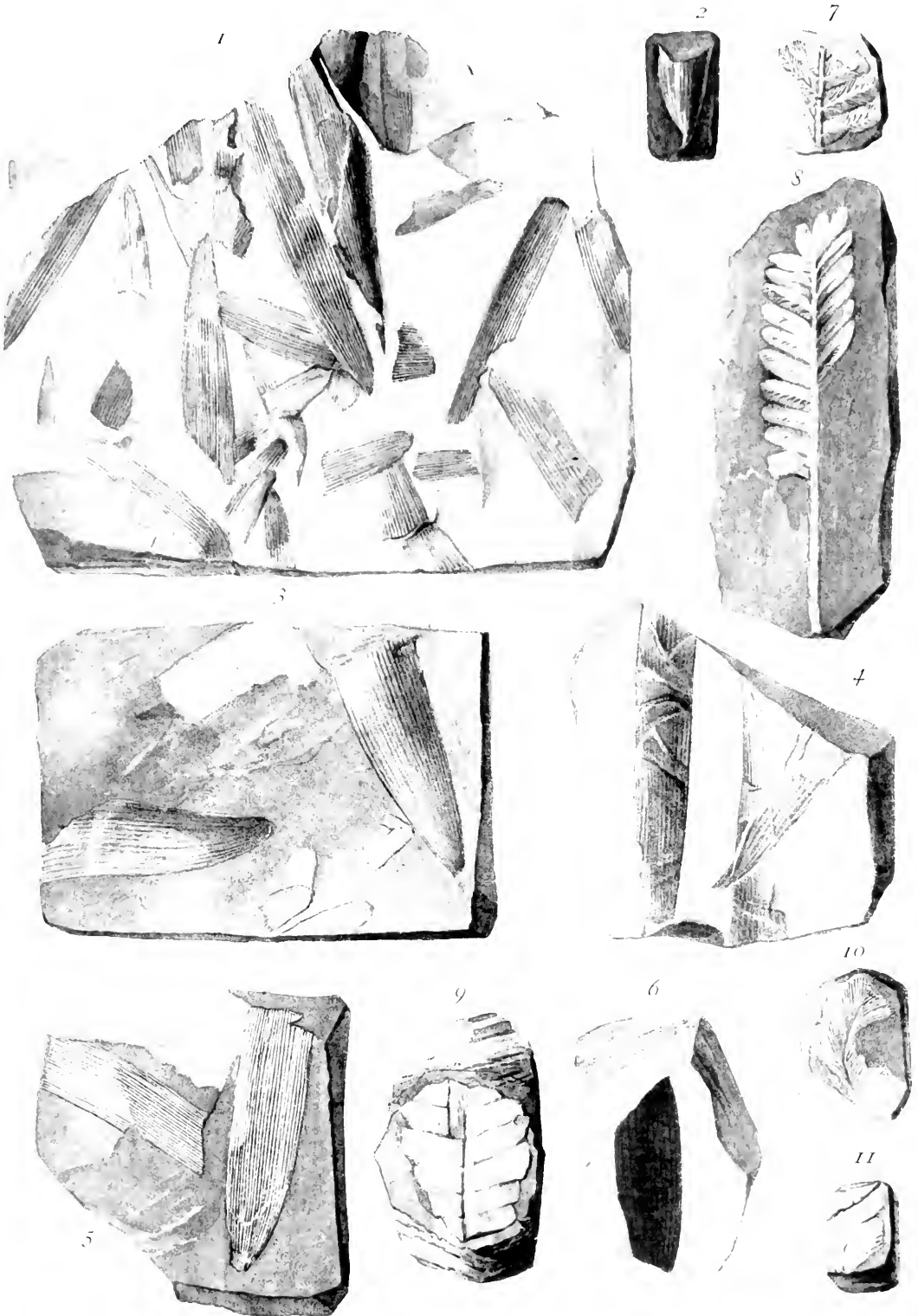
PLATE IV.

Plate IV.

Jurassic Plants.

Chiang-hsi.

- Fig. 1. *Podozamites lanceolatus* (LINDL. ET HUTT.). Kao-kang.
Fig. 2. *Podozamites lanceolatus* (LINDL. ET HUTT.). San-chia-chung.
Fig. 3. *Podozamites lanceolatus* (LINDL. ET HUTT.). Sha-shih-chieh.
Fig. 4. *Phœnicopsis latior* HEER. Sha-shih-chieh.
Figs. 5, 6. *Podozamites lanceolatus* (LINDL. ET HUTT.). Ch'ung-chia-fang.
Figs. 7, 8. *Cladophlebis* sp. Liao-chia-shan.
Fig. 9. *Pterophyllum* ? sp. Ssu-lu-p'u.
Fig. 10, 11. *Nilssonina* ? sp. Ssu-lu-p'u.



M. YOKOYAMA.
MESOZOIC PLANTS FROM CHINA.

PLATE V.

Plate V.

Jurassic Plants.

Ta-shih-ku (Ssu-ch'uang).

Fig. 1a. *Todites Williamsoni* (BRONGS.).

Fig. 1b. *Carpolithes globularis* n. sp.

Triassic Plants.

T'ang-t'ang (Yün-nan).

Fig. 2. *Glossopteris* (?) sp.



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MESOZOIC PLANTS FROM CHINA.

PLATE VI.

Plate VI.

Jurassic Plants.

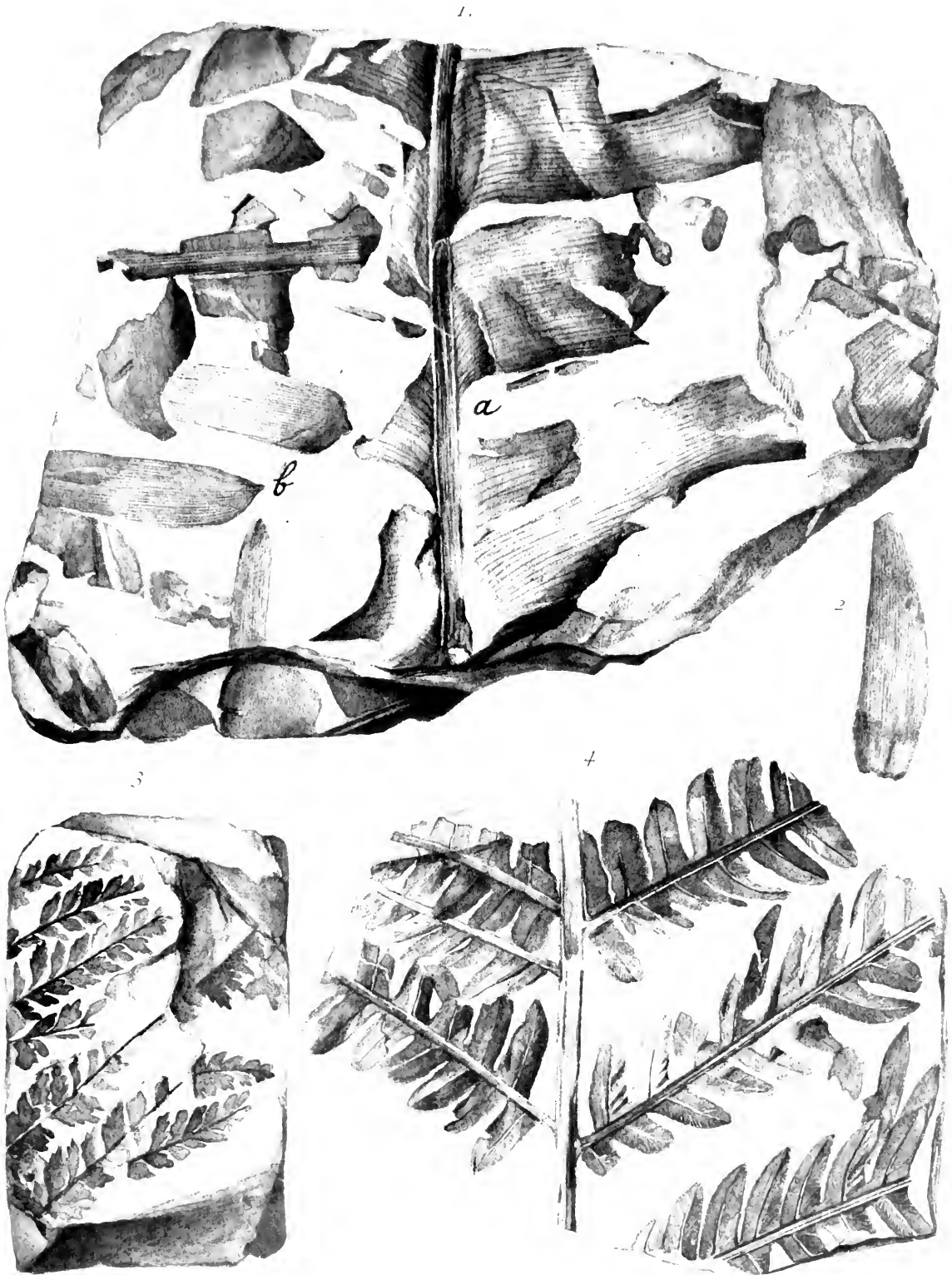
Fang-t'u (Shan-tung).

Fig. 1a. *Ctenis* sp.

Figs. 1b, 2. *Podoxamites lanceolatus* (LINDL. ET HUTT.).

Fig. 3. *Coniopteris hymenophylloides* (BRONGN.).

Fig. 4. *Todites Williamsoni* (BRONGN.).



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MESOZOIC PLANTS FROM CHINA.

PLATE VII.

Plate VII.

Jurassic Plants.

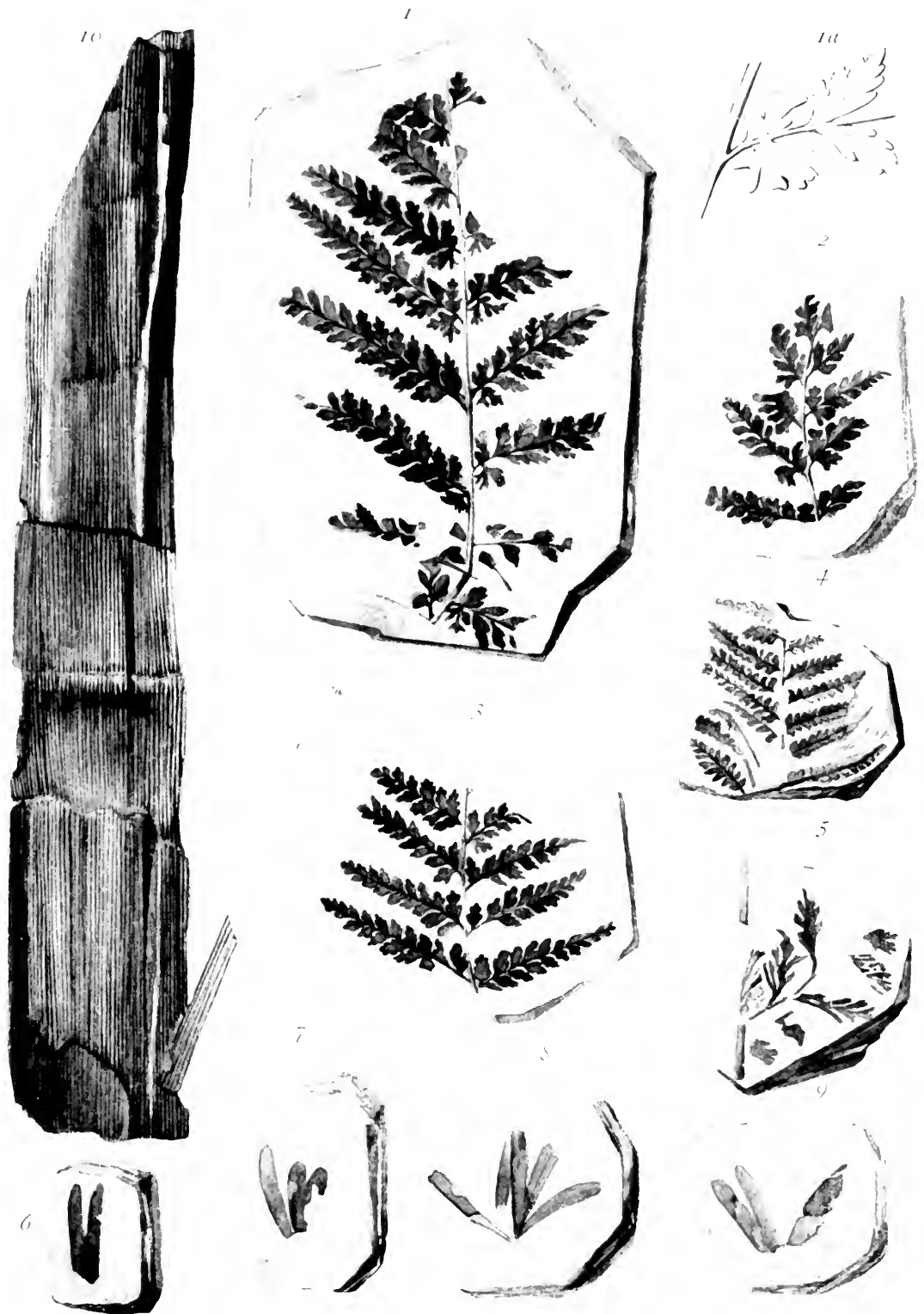
Lao-tung-ts'ang (Chih-li).

Figs. 1, 1a, 2-5. *Coniopteris hymenophylloides* (BRONGN.).

Figs. 6-9. *Ginkgo flabellata* HEER.

Nien-tzu-Kou (Shêng-ching).

Fig. 10. *Schizoneura hœrensis* (HISINGER.)



M. YOKOYAMA
MESOZOIC PLANTS FROM CHINA.

PLATE VIII.

Plate VIII.

Jurassic Plants.

Nien-tzu-kou (Shêng-ching).

Fig. 1. *Todites Williamsoni* (BRONGN.).

Fig. 2, 2a. *Palyssia manchurica* n. sp. 2a showing the enlarged leaves.



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MESOZOIC PLANTS FROM CHINA.

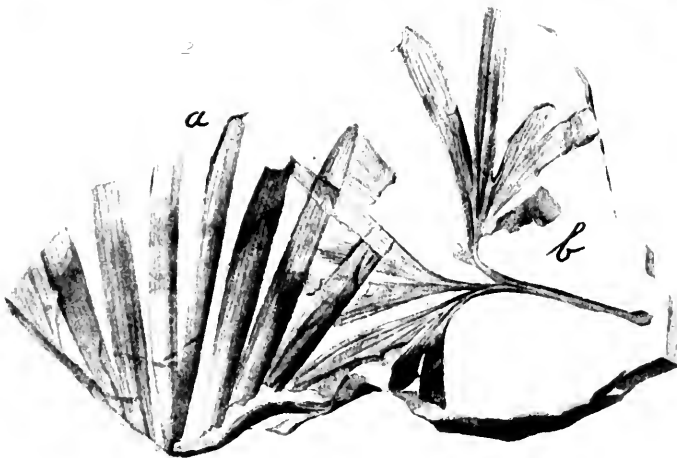
PLATE IX.

Plate IX.

Jurassic Plants.

Nien-tzu-kou (Shêng-ching).

- Fig. 1. 1a. *Ctenis Kancharai* n. sp. 1a showing the venation.
Fig. 2a. *Baiera gracilis* BUNB.
Fig. 2b. *Ginkgo lepida* HEER.



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MESOZOIC PLANTS FROM CHINA.

PLATE X.

Plate X.

Jurassic Plants.

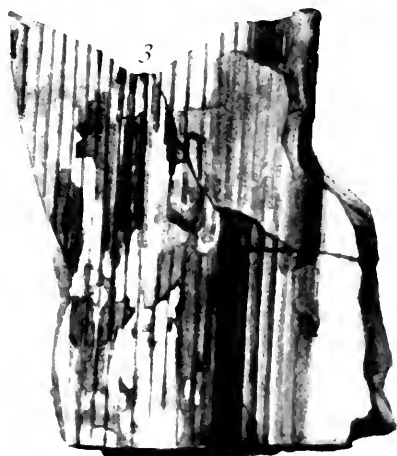
Nien-tzu-kou (Shêng-ching).

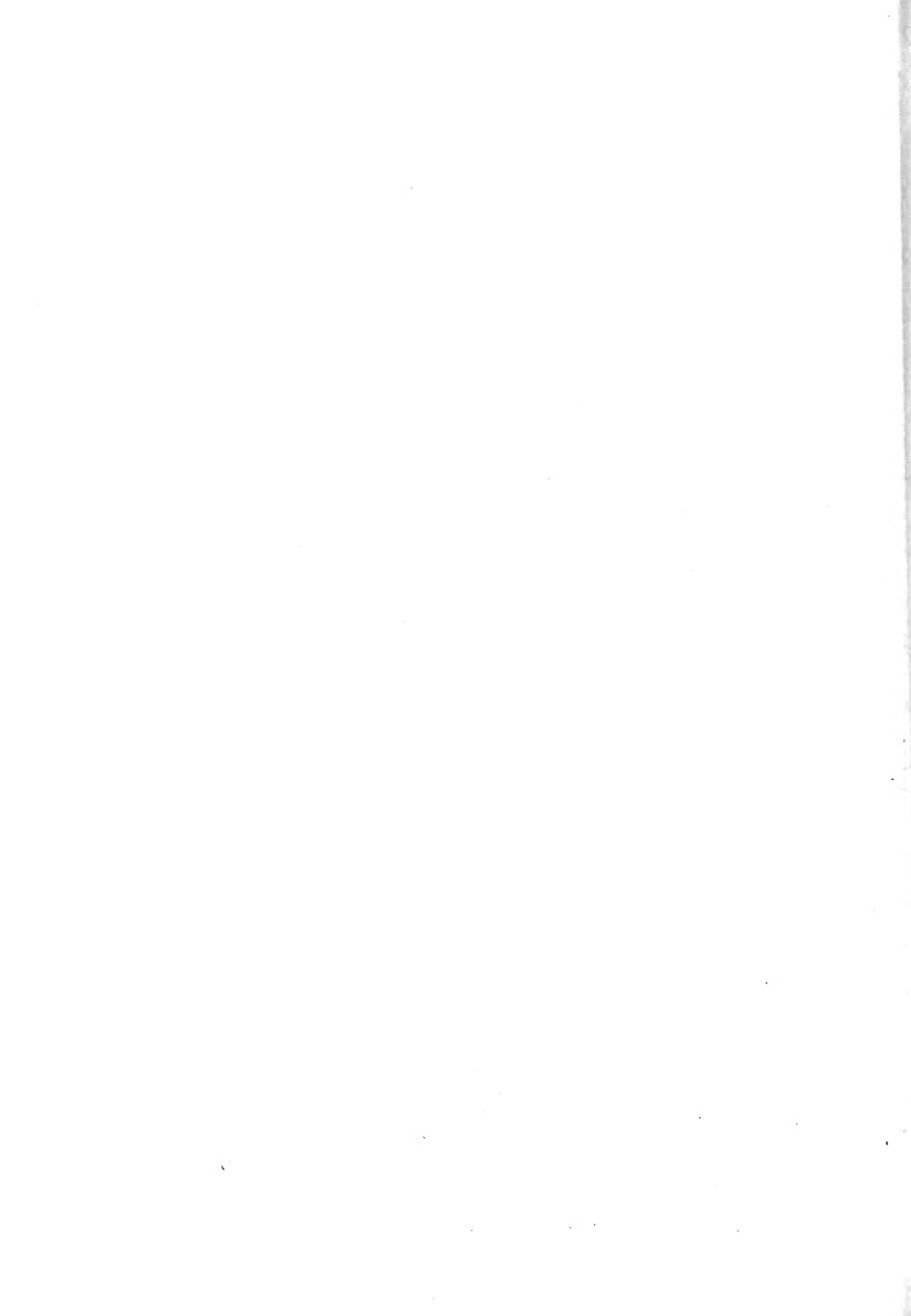
Fig. 1. *Czekanowskia Murrayana* (LINDL. ET HUTT.).

Lung-wang-tung (Ssu-ch'uang).

Fig. 2. *Schizoneura hœrensensis* (HISINGER)?

Fig. 3. *Equisetaceæ*.





M. YOKOYAMA.
MESOZOIC PLANTS FROM CHINA.

PLATE XI.

Plate XI.

Jurassic Plants.

Sha-ho-tzu (Shêng-ching).

Fig. 1, 2. *Dioonites Brongniarti* (MANT.).

Ta-t'ai-shan (Shêng-ching).

Fig. 3. *Podoxanites lanceolatus* (LINDL. ET HUTT.).

Fig. 4-7. *Ginkgo* sp.

Pao-êrh-shan (Shêng-ching).

Fig. 8. *Phyllothecca* sp. Roots.





M. YOROYAMA.
MESOZOIC PLANTS FROM CHINA.

PLATE XII.

Plate XII.

Cretaceous Plants.

Ssu-ch'uang.

- Figs. 1, 1a. *Glossozamites Hoheneggeri* (SCHENK). Shi-huan-tzu.
Fig. 2. *Cladophlebis* sp. Sha-chi-miao.
Fig. 3. *Podozamites lanceolatus* (LINDL. ET HUTT.). Shi-huan-tzu.
Fig. 4, 4a. *Coniopteris nitidula* n. sp. Shi-huan-tzu.
Figs. 5a, 6? *Glossozamites Hoheneggeri* (SCHENK). Sha-chi-miao.
Figs. 5b, 7. *Glossozamites acuminatus* n. sp. Sha-chi-miao.



Acoustical Investigation of the Japanese Bamboo Pipe, Syakuhati.

By

T. Terada, *Rigakushi*.

Lecturer on Physics in the Tōkyō Imperial University.

With 3 plates.

Of all our wind instruments the *syakuhati* has for more than two centuries been one of the most popular with our people. Its origin is probably to be traced back to a similar pipe called the *hitoyogiri*, which was already popular under the Asikaga Shōgunate. It had been originally an inseparable accompaniment of a sect of itinerant Buddhist priests called *komusō*, and special melodies were composed for it. The characteristic color of its notes gave it a peculiar hold upon the fancy of the nation, which has steadily grown stronger until to-day it has become so popular that every favourite air is played on it and even a special system of written music has been developed for the instrument.

The timbre of the notes of the *syakuhati* somewhat resembles that of a flute and also that of an oboe, being peculiarly pathetic and of a rural color. The characteristic variety of expressions and tone-colors, of which it is capable is not attainable by any other instrument of the kind.

The name *syakuhati* is derived from the length of the pipe, which is 1 *syaku*¹⁾ and 8 (*hati*) *sun*, for the Japanese key *itikotu* (d). However, in pipes in popular use the length differs, varying from ca. 1.2 *syaku* to 2.1 *syaku*. To give the octaves of the proper *syakuhati* a pipe 1.2 *syaku* long is used. Of late, the instrument has been occasionally played with a violin, in unison after the Japanese manner. In this case the length of the pipe is 2.1 *syaku*, giving c, for the gravest tone.

Moreover, a simple melody is often played in unison with two pipes of different lengths, 1.7 and 1.9 *syaku*, using different positions of the finger-holes for the two pipes, whose gravest tones differ by an interval of a whole tone.

The pipe is cut from well seasoned bamboo (*Phyllostachys Quiloi*, Riv.) near its root in such a way that both its ends correspond to knots in the bamboo. The compactness of the tissues is the important factor determining the quality of the note. The bamboo must be neither too hard nor too soft. This compactness is in some measure estimated from its density. There is a traditional receipt for the choice of the bamboo viz., that a proper *syakuhati* with a periphery of 3.7 *sun* at the uppermost finger hole, must have weight of about 100 *momme*=375 gr., when perfectly dried.

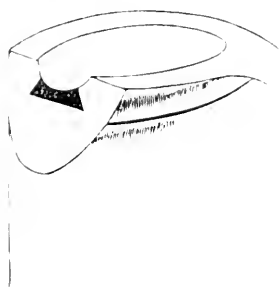
In Pl. I, is reproduced a photograph of a *syakuhati* in the possession of Mr. R. Uehara of the Tōkyō Musical Academy, a virtuoso on the instrument. The pipe has five lateral openings, four in front, the uppermost being at the back. The centre of the upper front hole is always a little above the middle of the pipe. The lengths occupied by the consecutive front holes are ca. 1/9.5 of the total length. The distance between the back hole

1 1 *syaku*=10 *sun*=0.30303 m.

and the upper front hole measured along the length of the pipe is ca. 0.75 of the length occupied by the consecutive front holes.

The number of knots of a proper *syakuhati* must be seven. Of these the two at the ends, and the one immediately below the lowest hole, i.e. about 3 *sun* from the lower end, are considered very important for giving strength to the pipe and for insuring the proper tuning. The latter, on this account, has received the special name, *gorobusi*. Between this knot and the lower end, two or three knots are required. According to the natural distribution of knots in the bamboo plant, the distances between consecutive knots increase toward the upper end of the pipe. In the traditional form of the *syakuhati*, the distances between consecutive knots, excluding those situated between the *gorobusi* and the lower end, must form a harmonic series of 3, 4, 5 and 6 *sun*, making 18 in all. Such an ideal form is rarely met with. Also the fact that the two ends must correspond to knots, greatly restricts the choice of the bamboo. To obviate this difficulty, an improvement has recently been made which consists in joining up the pipe from two separable halves. This modification alters the quality of the pipe in no sensible way.

The lower part of the pipe usually bends forward with a slight curvature. The most conspicuous feature of the instrument is the embouchure. It is called the *utaguti* (*uta*=song; *kuti*=mouth)

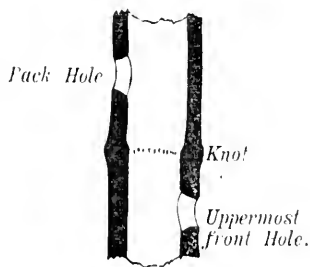


as in other wind instruments of the kind. A part of the thick wall in front of the upper end is beveled with a plane making an angle of about 30° with the downward direction of the length, so that a portion of the inner wall forms a sharp

knife-edge. For the bamboo knife-edge an imbedded piece of horn, whale bone, ivory, etc., is usually substituted to prevent wearing. The back part of the upper end is rounded off with a slight inclination backward, so that when the end is applied between the lower lip and the chin, it may fit uniformly to the chin. The general aspect of the embouchure may be seen in the annexed figures.

The interior of the pipe is cleared of the septa at the knots and carefully varnished with reddish Japanese lacquer. In some pipes, the septa are entirely removed, so that in the interior no abrupt change of the section exists; whereas, in other pipes, the septa are imperfectly removed so that in the joint below each knot, the section of the pipe is slightly narrowed. In any pipe, the inner diameter decreases slightly toward the *gorobusi* at which the section is narrowed somewhat abruptly. Below this contraction, the calibre is uniform, or gradually widens towards the lower end, according to the fancy of the constructor.

The lateral openings are generally of a circular or slightly elliptical shape. Their areas are determined with some proportion to the sectional area at the *gorobusi*. For many pipes the third hole, counted from the lower end, is made a little narrower than the others, in order to secure the proper tuning. The hole gradually widens toward the inside, as shown in the annexed figure, which shows a portion of the longitudinal section of a pipe. Generally, the position and width of each hole slightly differ for different pipes, according to the irregularities of the sections. Irregularities on the inside of the lateral openings more or less affect the pitch of overtones.



The lacquering of the inner wall is necessary in order to secure the easy production of the notes. A roughness of the interior also prevents the clearness of the notes, and lowers the pitch sensibly. If the inside of an unvarnished pipe be wet throughout with water, its note is remarkably improved.

In playing the pipe, the embouchure is applied between the lower lip and the chin so that a narrow arcular aperture is left between the lip and the knife-edge, upon which the jet of air from the mouth is directed. The pipe is held by its lower part between the thumb and the middle finger of the right hand so that the middle finger rests midway between the lower pair of front holes. The left hand holds the upper part of the pipe, the thumb corresponding to the back hole, and the middle finger being placed between the upper pair of front holes. The distribution of the other fingers will be understood. The lower end of the pipe should be placed a few cm. above the right knee when the player is seated. To produce the note, the lips must be contracted a little, so as to rightly direct the jet of air upon the knife-edge. Thus, the cavity of the mouth of the player, the narrow opening between the lips and the knife-edge, taken as a whole, makes up a special form of the embouchure of an organ pipe. The adjustment of the lips is not an easy matter for beginners so that for most persons it takes a week of training, before a tolerable clear sound is produced.

The most conspicuous characteristic of this pipe is that the pitch of the several notes corresponding to the different positions of the holes, may be varied within a wide range, by simply adjusting the area of the arcular aperture of the embouchure. This adjustment is usually made by changing the inclination of the head of the player, relative to the pipe. The angle through

which the adjustment may be made measures about 10", producing a change in the note of more than a semitone. To raise or lower the note, the head is inclined so that the arcular aperture is slightly widened or narrowed, while the pipe is held almost immovable. The raising or lowering of the pitch produced in this way is called respectively the *kari* or *meri* of the sound. Besides this adjustment, a slight lowering of the pitch is often effected by placing the finger immediately above the corresponding hole, so as to prevent free communication of air through the hole. This adjustment, the action of which is called *kazasu* is rather difficult, so that it is only made by virtuosi. Since, in this way, the compass of the notes for consecutive positions overlap each other, the instrument is capable of producing almost *any note* within a range of nearly two octaves, notwithstanding the small number of its lateral openings.

In short, the instrument is to be regarded as an ingenious form of organ pipe which produces a continuous gradation of notes. In this respect, the *syakuhati* may be compared to a string instrument such as a violin rather than to wind instruments of its kind. The smooth slurring of the note by a semitone which is frequently met with in many Japanese melodies, executed on this instrument, is peculiarly sweet. The extraordinary variability of the note makes the technics of the pipe much more difficult than in the case of other instruments. Except when guided by a good ear, the homophonic performance of a melody by two *syakuhati* is not an easy matter.

It may be added that beginners are apt to make the mouth opening too narrow by a striving to produce the notes, so that the pitch are generally lowered.

The principal objects of the present investigation are to

examine the special function of the mouth in producing the varieties of the notes and also to study the effects of the lateral openings in general. The latter part, therefore, may be applied to any other instrument with lateral openings. In addition, the effect of obstacles placed inside the pipe is dealt with, with reference to the knots of the *syakuhati*.

RESULTS OF THE EXPERIMENTS.

1. Notes in different Positions.

The *syakuhati* upon which the experiments were made, was of the following dimensions :

The length of the pipe from end to end = 49.2 cm.

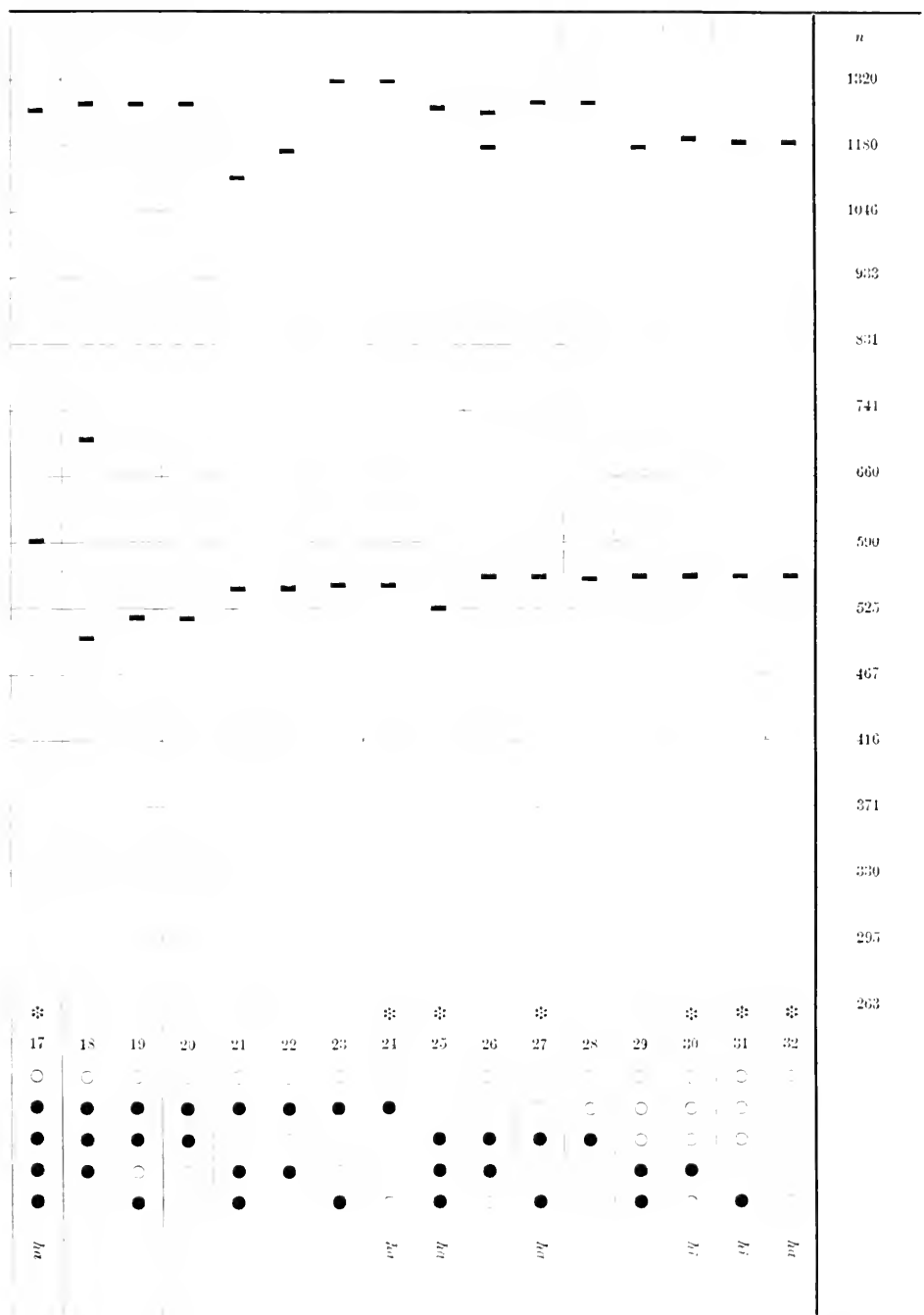
The distances of the centers of the holes from the upper end = 19.8, 23.4, 28.3, 33.3 and 38.2. cm.

The mean diameter of the finger-holes = 0.9 cm.

The diameter of the section immediately inside the mouth = 1.9 cm.

Ditto at the *gorobusi* = 1.5 cm.

Approximate pitches of the notes for all the possible combinations of holes for a nearly constant width of the mouth are tabulated as follows :—



The pitch for each position varies of course with different widths of the opening of the embouchure, with the pressure of the breath, and also with the degree of the opening of the finger-holes. In the above table, the fundamental tone was obtained by a very light breath-pressure in order that it might not deviate much from the natural pitch: on the contrary, the overtone can be obtained only by somewhat strong pressure. When blown forcibly as in actual playing, the fundamental tone is raised about a semitone so that the overtones for the positions 1, 2, 4, 8, 16, 17, 30, 31, 32 become the octaves of the corresponding fundamental tones. It will be noticed that the overtones of the other positions are very much complicated with respect to their fundamental notes. While the fundamental notes are generally lowered more or less by closing the hole below the uppermost open one, the contrary is often the case with the overtones as in the positions 5, 7, 9, 10, 12, etc. Besides, an overtone much lower than the octave is met with in the position 9 and 18.

2. Correction for the Mouth.

How much the natural pitch of the pipe is influenced by varying the area of the mouth-opening may be shown by the following simple experiment. The embouchure is brought to the lip, as in playing. Bring a proper vibrating tuning fork near the embouchure and adjust the aperture so that the resonance is maximum. If the pipe be slightly inclined from this position or if the lower lip be slightly moved, the resonance at once falls.

For an ordinary organ pipe of a circular section, the correction which is to be added to its length in order to obtain the fractions of the wave length, is according to Cavaillé-Coll, $3\frac{1}{2} R$,

where R is the sectional radius of the pipe. Lord Rayleigh¹⁾ pointed out that the greater part of it is due to the embouchure. As far as I am aware, there has been no further experimental investigation with respect to the details of the relations between the dimension of the embouchure and the correction due to it.

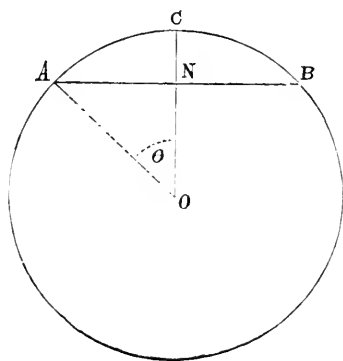
In the case of the *syakuhati*, the mouth opening is very narrow, being an arcular passage between the lip and the sharpened edge of the embouchure, so that the correction of the length due to the embouchure may be expected to be very great. As may be seen later, it is in some cases ten times the sectional area of the pipe.

To study the effect of the embouchure directly on the *syakuhati*, is not very easy, 1) because the determination of the area of the irregular mouth-opening between the lip and the edge, is difficult; the more so, since the area is varied seriously by a slight motion of the lip; 2) because the effect of the lateral openings interferes with that of the embouchure if we wish to examine the cases for various notes. I sought, therefore, for a simple form of resonator which was similar to the *syakuhati* in the essential form of the embouchure and which enabled me to study the effect of the embouchure only, free from the complications due to the lateral openings. The experiment made for this purpose was as follows.

A glass pipe with a fairly uniform inner diameter of 3.95 cm. and a thickness of 2.7 mm., was fixed vertically. The upper, open end was polished carefully, while the the lower end was stopped with a cork, through a hole in which a small glass tube was inserted. Through this small tube, water was introduced

1) Rayleigh, Phil. Mag., 3, 462, 1877.

into or removed from the lower part of the pipe, in order to adjust the length of the air column inside the pipe at will. A thin plate of zinc, 0.4 mm. thick, was fastened on the open end to cover it partially, leaving



a segmentary aperture between its straight edge and the edge of the pipe. In order to secure a close contact between the plate and the polished end of the pipe, a small quantity of tallow was applied to the place of contact. The area of the segmentary aperture was calculated

from the length of the arrow. In the annexed figure, the area of the segment ABC is given by

$$r^2\theta - \frac{r^2}{2}\sin 2\theta,$$

where

$$\theta = \cos^{-1} \frac{r-p}{r},$$

r being the radius and $p = CN$. A strip of glass graduates throughout its entire length was applied to aperture so that its end came into contact with the edge of the zinc plate and the value of p was estimated to the tenth of a millimeter.

The tuning forks used consisted of a set of 13 forks giving a tempered chromatic scale within the range of c_1 to c_2 . The number of vibrations of these forks had been previously determined approximately in comparison with a set of standard forks made by Koenig. For lower notes, Koenig's forks giving Sol, Mi_2 , and Ut_2 were employed.

First the air column within the pipe was adjusted to a desired length l . The different forks were successively brought

near the aperture, the zinc plate was so adjusted that the resonance was maximum and then the corresponding value of p was measured. Next the length of the air column was changed and the procedure was repeated. The result of these experiments gave the relation between the dimensions of the embouchure and the proper pitch of the resonator for different lengths of the air column. The results are given in Fig. 3 in which the abscissa is the number of vibrations of the resonator and the ordinate is the fourth root of the area of the aperture σ . From the diagram, it will be seen that:

1. The curves n to $\sigma^{\frac{1}{4}}$ for different values of l seems to converge toward the origin with a slight curvature.

2. When the length of the air column becomes comparable with its diameter, as for $l=5.23$ cm., the number of vibrations is nearly proportional to $\sigma^{\frac{1}{4}}$.

3. The greater the length of the air column, the slower the pitch rises with the increase of the aperture.

4. The narrower the area of the aperture of the embouchure the greater is the ratio $\frac{\partial n}{\partial \sigma^{\frac{1}{4}}}$.

Care was duly taken not to bring the tuning fork so near to the aperture of the embouchure as to affect the natural pitch.

The effect of the moisture in the air column was calculated and found to be insensible within the required range of accuracy.

The pitch of a simple resonator having its three dimensions comparatively smaller than the wave length and communicating with the external atmosphere by a small opening in its surface, has been investigated by many eminent physicists. Helmholtz¹⁾ obtained theoretically for a circular aperture,

1) Helmholtz, Crelle, Bd. LVII. 1-72. 1860.

$$n = \frac{a\sigma^{\frac{1}{2}}}{2^{\frac{1}{2}}\pi^{\frac{1}{2}}S^{\frac{1}{2}}},$$

where S is the volume and a the velocity of the sound wave in air. Sondhauss¹⁾ obtained experimentally

$$n = 52400 \sigma^{\frac{1}{2}} S^{\frac{1}{2}} \quad (\text{length in mm.})$$

These results have been discussed by Lord Rayleigh²⁾ in his classical paper on resonance. On the other hand, the correction for the open end of a cylindrical resonator has been treated both experimentally and theoretically by many physicists,³⁾ beside the worthies above quoted. The present experiments furnish in some measure the intermediate stage of transition from the first case to the second. As will be seen from the above result, when the length of the air column is small, the pitch is nearly proportional to $\sigma^{\frac{1}{2}}$ and also nearly so with $l^{-\frac{1}{2}}$ or $S^{-\frac{1}{2}}$; and when the area of the aperture gradually approaches a complete circle, the curves n to $\sigma^{\frac{1}{2}}$ tend to the values given by the previous results for the open pipe.

It is an established fact that for a similar resonator, the pitch is inversely proportional to its homologous dimensions. Hence, the above results may be applied to other pipes with different diameters, if n and $l^{-\frac{1}{2}}$ be multiplied by the ratio (the diameter of the glass pipe above experimented on / the diameter of the other pipe) and $\sigma^{\frac{1}{2}}$ by (the same ratio).⁻¹

1) Sondhauss, Pogg. Ann. LXXXI. pp. 245, 357, 1850.

2) Rayleigh, Phil. Trans. CLXI. pp. 77-118.

3) Poisson, Mem. de l'Acad. des Sci. 1817, II, 305. Savart, Ann. d. Chim. t. XXIV, 1823. Hopkins, Cam. Phil. Trans. V, 1838. Quet, Journ. d. Liouville, XX, 1, 1855. Wertheim, Ann. d. Chim. et Phys. (3), XXIII, 434; and XXXI, 385, 1848-51. Zammmer, Pogg. Ann., XCVII, 183, 1856. Gripen, Ann. d. Chim. III, 384, 1874. Rayleigh, Phil. Mag. (5) III, 456. Bosanquet, ibid IV, 291, 1877; and VI, 63, 1878. Koenig, Wied. Ann. 569, 1881. Blaikley, Phil. mag. (5) VII, 339, 1879.

Heinholdtz, Crelle, Bd. 57, 1860; Gesammelte Abhandlungen Bd. I.

The effect of the thickness of the pipe or of the plate is very small, provided it is very small in comparison with the wave length. The relation above obtained is, therefore, applicable also to the case of the *syakuhati* as shown in the latter part of this paper.

3. Lateral Openings.

Lord Rayleigh¹⁾ in his paper on resonance, has suggested a method for the theoretical treatment of the lateral openings of wind instruments. However, as far as I am aware, no further result either theoretical or experimental has been published. The necessity of investigating the functions of the lateral openings for the explanation of the phenomena connected with the *syakuhati*, led me to undertake a series of experiments which I shall now describe.

A cylindrical pipe was made of a zinc plate, 0.5 mm. thick, with an inner diameter of 4.0 cm. and a length of 1 m. A long scale printed on paper was attached to the side of the cylinder. A cylindrical tank with a depth of over 1 m., was filled with water in which the cylindrical pipe was inserted vertically so as to vary the length of the air column inside the resonator when the pipe was raised or lowered by hand. Lateral holes of different diameters were made in the side of the pipe at different positions. For different positions of the holes, the lengths of the air columns were determined which give respectively the maximum resonance for different tuning forks.

For the degree of accuracy required for the present purpose, the raising or lowering of the pipe could conveniently be done with one hand, while the other hand held the fork near the

1) Rayleigh, loc. cit.

opening. Arrangements which in the earlier part of the experiment had been used for guiding the motion of the pipe and for reading its height were afterward dispensed with. The verticality of the pipe was approximately secured by a straight brass rod fixed parallel along the side of the pipe at a distance of 2.5 cm, this rod being held in contact with the side of the tank during the raising and lowering of the pipe.

Holes which had to be covered, were closed air-tight with curved plates of zinc closely fitting the side of the pipe, and sealed with a kind of tallow. The slight irregularity on the inner wall of the pipe due to the closing of the hole in this way, was found to affect the velocity of sound within the pipe in no sensible degree.

The results of the experiments are summarized below :

a) Correction for the open end.

First, the correction of the length due to the open end only was determined in the usual manner, before any holes were made. The results gave $0.42 R$ for the mean value, where R is the sectional radius of the pipe.

b) One circular hole.

In Figs. 4, 5 and 6, the relation is given between the distance d of the center of the hole from the open end and the total length L , from the open end to the water surface which gives the maximum resonance for different tuning forks. The difference of the ordinate between the curve and a straight line through the origin making an angle of 45° with the axes, gives the distance l of the center of the hole from the water surface. The value of $\frac{\lambda}{2} - l = d$ where λ is the wave-length corresponding to the note, may be considered as the correction due to the lateral opening. It will be seen that the correction increases first

slowly with d and then rapidly when d approaches the half wave length. The rapidity of the increase of the correction α with d , depends on the width of the lateral hole. Fig. 7. shows the relations between d and α , for c_1 , corresponding to three different values of the diameter of the hole r . The curves have very long inflexions so that when d is neither very small nor near the half wave length, they may be regarded as approximately straight lines apparently converging to a point on the axis of d .

For different notes with different wave lengths, it was found that if the curves be drawn for different notes representing the relation of α and $\frac{d}{\lambda}$ (instead of d), they coincide with each other very closely except when $\frac{d}{\lambda}$ is nearly $\frac{1}{2}$. This is true for holes with different areas.

When d becomes greater than $\frac{\lambda}{2}$, the relation is quite similar to what it would be if the pipe were cut off at a distance equal to $\frac{\lambda}{2}$ from the open end. If the upper end of the pipe be perfectly closed by a rigid plate, the results are similar to those obtainable in case the pipe were prolonged by a length $=\frac{\lambda}{4}-0.4 R$ and the rigid plane were removed. If, again, the open end be partially closed with a plate having a circular hole, the case is quite similar to what it would be if the tube were produced by $\frac{\lambda}{4}-c$ where c is the correction of the length due to that partial opening. The latter fact has been verified experimentally with several mouth plates, with different diameters, the corrections due to which had been previously determined. Thus, α is periodic with respect to $\frac{d}{\lambda}$, with the exact period of $\frac{1}{2}$.

c) Several holes.

When more than one hole is made, the case becomes much complicated, since the different combinations of holes produce a great number of cases which must be investigated independently.

From the results of the experiments, we may infer generally that the correction α for any one hole is diminished by making another hole nearer the open end, and that the diminution increases with the width of the second hole and with its approach to the first hole. In Figs. 4, 5 and 6, the dotted lines give the value of l when a similar hole is made at s cm. from the first opening. It will be seen that for the diameter of holes = 1.8 cm., the effect of the second hole is to make the curve α to $\frac{d}{\lambda}$ almost parallel to the axis of $\frac{d}{\lambda}$.

The correction α diminishes almost uniformly with the decrease of the distance separating the two holes; and the rate of the diminution increases with the diameter of the second opening or with the number of further openings if such be present; but it is nearly independent of the distance of the first opening from the open end. The relation may be seen from the following tables :—

TABLE I.

Diameter of holes=5 mm.

Distances of holes from the open end=0.7, 6.75, 11.75, 16.75 and 21.75 cm.

$\left\{ \begin{array}{l} L = \text{Length of air column for maximum resonance, in cm.} \\ \alpha = \text{Quarter wave length minus the distance between the closed end and the open hole nearest to it, in cm.} \\ \circ : \text{opened.} \\ \times : \text{closed.} \end{array} \right.$

						$t=15^{\circ} C$			
Positions of Holes						$c_1 : \frac{\lambda}{4} = 31.9 \text{ cm.}$		$f_1^{\#} : \frac{\lambda}{4} = 22.5 \text{ cm.}$	
closed end \longrightarrow opened end						L	α'	L	α'
1	o	o	x	x	x	42.6	11.1	32.4	11.8
2	o	x	o	x	x	41.5	12.2	30.9	13.3
3	o	x	x	o	x	40.7	13.0	29.5	14.7
4	o	x	x	x	o	39.9	13.8	28.4	15.8
5	o	x	x	x	x	39.8	13.9	28.3	15.9
6	o	o	o	x	x	43.8	9.9	33.3	10.9
7	o	x	o	o	x	41.9	11.8	31.5	12.9
8	o	x	x	o	o	40.8	12.9	29.7	14.5
9	o	o	o	o	x	43.9	9.8	33.8	10.4
10	o	x	o	o	o	42.0	11.7	31.6	12.6
11	x	x	o	o	x	35.5	8.2	25.8	8.4
12	x	x	o	x	o	34.6	9.1	24.9	9.3
13	x	x	o	x	x	34.5	9.2	24.8	9.4

TABLE II.

Diameter of holes=1 cm.

Distances of holes from the open end=0.8, 6.75, 11.75, 16.75,
21.75 and 31.75 cm. $t=15^\circ C$

Positions of Holes closed end \longrightarrow opened end	$c_1 : \frac{\lambda}{4} = 31.9 \text{ cm.}$		$f_1^\# : \frac{\lambda}{4} = 22.5 \text{ cm.}$	
	L	a	L	a
1 O . O X X X X	55.4	8.3	44.8	9.4
2 O . X O X X X	54.8	8.9	43.5	10.7
3 O . X X X O X	53.2	10.5	39.2	15.0
4 O . X X X X X	52.0	11.7	34.7	19.5
5 X . O O X X X	46.8	6.9	37.1	7.1
6 X . O X O X X	45.9	7.8	35.8	8.4
7 X . O X X O X	45.1	8.6	34.8	9.4
8 X . O X X X O	44.7	9.0	33.8	10.4
9 X . O X X X X	44.5	9.2	33.6	10.6
10 X . O O O X X	47.4	6.3	37.7	6.5
11 X . O X O O X	46.2	7.5	36.1	8.1
12 X . O X X O O	45.3	8.4	34.9	9.3
13 X . O O O O X	47.6	6.1	38.1	6.1
14 X . O O X O X	47.1	6.6	37.3	6.9
15 X . X O O X X	42.5	6.2	32.7	6.5
16 X . X O X O X	41.6	7.1	31.8	7.4
17 X . X O X X O	40.9	7.8	30.8	8.4
18 X . X O X X X	40.9	7.8	30.6	8.6
19 X . X X O O X	37.8	5.9	28.3	5.9
20 X . X X O X O	36.9	6.8	27.4	6.8
21 X . X X X O O	33.8	4.9	24.3	4.9

TABLE III.

Diameter of holes=1.8 cm.

Distances of holes from the open end=11.7, 21.7, 31.7, 41.7,
and 51.7 cm. $t=15^{\circ} C$

Positions of Holes closed end \longrightarrow opened end						$c_1 : \frac{\lambda}{4} = 31.9 \text{ cm.}$		$f_1^{\#} : \frac{\lambda}{4} = 22.5 \text{ cm.}$	
						L	a	L	a
1	o	o	x	x	x	79.6	4.0	—	—
2	o	x	o	x	x	78.9	4.8	68.3	5.9
3	o	x	x	o	x	78.1	5.5	64.9	9.3
4	o	x	x	x	o	77.2	6.4	—	—
5	o	x	x	x	x	73.5	10.1	—	—
6	x	o	o	x	x	69.7	3.9	59.8	4.4
7	x	o	x	o	x	69.1	4.5	58.8	5.4
8	x	o	x	x	o	68.3	5.3	56.4	7.8
9	x	x	o	o	x	59.8	3.8	50.0	4.2
10	x	x	o	x	o	59.1	4.5	49.0	5.2
11	x	x	x	o	o	49.8	3.8	40.1	4.1

For this value of the diameter of holes, the effect of a third hole is almost insignificant.

If the second hole be wider than the first, the rate of diminution of a with the decrease of the distance between two holes is greater than in the case where the two holes are of an equal area. This is shown by the following table when compared with Table I.

TABLE IV.

○ : diameter = 0.5 cm.

⊙ : „ = 1.0 cm.

Distances of holes from the open end = 0.8, 6.75, 11.75, 16.75 and 21.75.

					$t = 15^\circ C$			
Positions of Holes					$c_1 : \frac{\lambda}{4} = 31.9 \text{ cm.}$		$f_1^* : \frac{\lambda}{4} = 22.5 \text{ cm.}$	
closed end \longrightarrow opened end					L	a	L	a
○	⊙	×	×	×	44.5	9.2	34.5	9.8
○	×	⊙	×	×	42.9	10.8	32.5	11.8
○	×	×	⊙	×	41.3	12.4	30.5	13.8
○	×	×	×	⊙	39.9	13.8	28.6	15.7

4. Effects of Knots.

Lord Rayleigh¹⁾ proved that any slight contraction or expansion of the section of a cylindrical resonator affects more or less its natural pitch and that a broadening at the loop or a contraction at the node raises the natural pitch. The case treated by him is confined to the case where the variation of the section is very gradual. In the case of the *syakuhati*, the change of the section due to the knots is rather abrupt though small in amount. In order to test the effects due to diaphragms placed in a cylindrical resonator, the following simple experiments

1) Rayleigh, Theory of Sound. II.

were carried out. The cylindrical glass pipe used in the previous experiment for the effect of the aperture of the embouchure was fixed horizontally. The length of the air column inside the pipe was adjusted by means of a wooden piston around which a sheet of cloth was wound so that it fitted tightly to the inside of the pipe. Diaphragms were made of wooden cylinders of different lengths bored with cylindrical or conical passages of different calibres. Their lateral sides were covered by velvet in order to secure close contact with the interior of the glass pipe. Each of them was placed in the resonator successively at different distances from the open end. The tuning forks of the series used in the previous experiments, were successively brought near the open end and the lengths of the tube giving the maximum resonance were determined.

First, the diaphragms with cylindrical passages of different diameters, were tested. The results of the experiments are given in Figs. 8, 9, and 10 in full lines, in which the abscissa is the distance of the middle section of the diaphragm from the open end, and the ordinate is the length of the air column measured from the open end to the piston. Horizontal dotted lines show the length of maximum resonance when no diaphragm is present. The difference of the ordinate between a curve in full line and the corresponding horizontal dotted line gives the correction of the length due to the corresponding combination of the diaphragm and the tuning fork. It will be remarked :

- a) That the curves for different notes are nearly parallel ;
- b) That the correction is negative when the diaphragm is

near the node, is null at a certain distance from it, and thence increases almost proportionally with its distance from the node.

c) That the correction increases with the decrease of the sectional area of the passage, first slowly and then rapidly, as is also shown in the following table :

TABLE V.

Length of the diaphragm=1 cm.

Diameter of the passage.	Correction due to the diaphragm when its end is at the open end.	
	ϵ_1	ϵ_2
4 cm.	0.0 cm.	0.0 cm.
3	1.3	1.3
2	4.2	3.3
1	15.4	9.1

The intensity of resonance falls rapidly with the decrease of the diameter of the passage, when it becomes small. When the passage is narrow, the pipe is rather to be regarded as a system of two resonators communicating with each other by a narrow passage. In such a system, two modes of the vibration are possible. The one mode which was experimented with above is that in which the phase of the air motion is everywhere nearly the same. The other mode, in which the motions in the two parts are opposite, however, was entirely left out of consideration. Indeed, when the intermediate passage becomes narrow, the former mode becomes faint, while the latter becomes predominant. This fact may easily be shown by experiments. For the present problem,

however, we confine our study to the former mode exclusively. The latter mode will, I hope, form the subject of a future communication.

The results when a conical passage was used, are given in Figs 8, 9, and 10, in broken lines; the diameter given there is that of the narrower end, the wider one being always 4 cm. i.e. equal to the inner diameter of the pipe. Here, again, the abscissa is the distance between the open end and the middle section of the diaphragm. The results are quite unaltered if the direction of the conical channel be inverted. It will be seen from the figures :

a) That the correction due to the diaphragm is about 0.4 times less than that of the corresponding cylindrical channel whose sectional diameter is equal to the diameter of the narrower end of the conical channel.

b) That the full line and the corresponding broken line intersect each other at a point near the corresponding horizontal dotted line. This shows that, where the effect of the diaphragm is null, its form and size are immaterial.

c) That the straight line joining these points of intersection for different notes, is directed toward the origin. This shows that the position at which the effect of the obstacle is null, is given by the ratio of the distance from the piston or the open end to the wave length of the note.

Lastly, the effect of the length of the diaphragm was studied. The result is shown in Fig. 11. It will be noticed that the correction increases with the length of the channel. Though in this case the length of the diaphragm ranges from 5 to 1 cm., the different curves are nearly concurrent to a point on the corresponding dotted line, if the abscissa be taken proportional

to the distance between the middle section of the diaphragm and the open end of the glass pipe.

Another way of studying the effect of diaphragms is as follows. Inside an ordinary organ pipe a diaphragm is so inserted that its position may be adjusted in any desired way; the pipe is blown by means of a regulated bellows; and the pitch of the pipe for different positions of the diaphragm is determined. The organ pipe used in my experiment was a wooden one with a rectangular section, giving a_1 for the fundamental tone. The diaphragm was made of wood, fitting tightly in the inside of the pipe and perforated with a channel having a rectangular section. The lateral side of the diaphragm was covered with cloth in order to secure close contact with the inner wall of the pipe. The diaphragm could be brought to any position by means of two thin rods of steel which were fixed to the diaphragm diagonally opposite to each other. If the diaphragm is gradually pushed into the pipe while it is being blown with a constant pressure, the pitch of the note gradually rises till a maximum is attained at the node of the pipe; whence the pitch falls gradually with the further position of the diaphragm. The results of the experiment are quite analogous to those in the former experiment.

For the case when the section of a nearly cylindrical pipe varies slightly, Rayleigh obtained

$$\Delta l = \int_0^l \cos \frac{2\pi x}{l} \frac{\Delta S}{S_0} dx$$

where Δl is the correction of the length due to the irregularity; l the length between the consecutive loop and node; ΔS the small variation of the section given as a function of x measured from the node along the length of the pipe; and S_0 the mean section.

This relation has been obtained on the supposition that the velocity of flow in every transverse section is uniform. The assumption does not hold in the cases investigated, since the abrupt change of the section at both ends of the diaphragm produces an irregular flow of the air. It will be interesting, however, to test the above relations for the present case.

Let $\mathcal{A}S = \text{const.}$ between $x = \xi + a$ and $\xi - a$, and elsewhere $= 0$. Then, we have

$$\mathcal{A}l = \frac{l}{\pi} \frac{\mathcal{A}S}{S_0} \cos \frac{2\pi\xi}{l} \sin \frac{2\pi a}{l}.$$

For $\mathcal{A}l = 0$, we obtain $\xi = \frac{1}{4}l$. This is nearly the case in Figs. 9 and 10.

If $\xi = l$,

$$\mathcal{A}l = -\frac{l}{\pi} \frac{\mathcal{A}S}{S_0} \sin \frac{2\pi a}{l}.$$

Therefore, if $a = \text{const.}$,

$$\mathcal{A}l \propto \mathcal{A}S \quad \text{or} \quad \propto (R-r)^2$$

where R is the radius of the cylinder and r that of the channel. This is verified qualitatively in the table given in p. 24.

Comparing the above formulae with the results given in Figs. 8, 9, and 10, we see generally that the actual values of $\mathcal{A}l$ are far greater than the theoretical values, the discrepancy increasing with the decrease of the radius of the passage. This shows that the disturbance due to the end of the diaphragm is considerable.

APPLICATIONS OF THE RESULTS OF THE EXPERIMENTS TO THE SYAKUHATI.

The results of the present experiments may be applied to the case of the *syakuhati* in the following ways:—

The position of the node when all the lateral openings are closed, is easily found, since the lower end must correspond to the loop, provided the usual correction for the open end is made. When the embouchure is adjusted so that the note is c_1^{\sharp} , for this position, the distance N of the node from the mouth must be

$$N = L + 0.8 R - \frac{\lambda}{4}$$

where L is the total length of the *syakuhati* = 49.2 cm.; R the inner radius = 1 cm.; $\frac{\lambda}{4}$ = 30.1 cm. ($t = 15^{\circ} C$).

$$\therefore N = 9.9 \text{ cm.}$$

Now, as already mentioned, Fig. 3 may be reduced to the case of a similar cylindrical resonator with its sectional diameter equal to that of the *syakuhati*. Since in the present experiment, the ratio of the diameter of the glass pipe used to the sectional diameter of the *syakuhati* is nearly 2, the value of n in the figure was multiplied by 2 and l was divided by 2. From the figure thus reduced, was found the value of the ordinate for which $\frac{\lambda}{4} - l$ for c_1^{\sharp} is 9.9 cm. For this value of the ordinate, a curve giving the relation l to n was drawn, whence the correction corresponding to any other note could be obtained. In this way, N for any position of the holes can be found, if we have only determined the number of vibrations of the notes corresponding to that position. We have

$$N = \frac{\lambda}{4} - \left(\frac{\lambda}{4} - l \right) = l.$$

$N + \frac{\lambda}{4}$ from the embouchure gives the position of the virtual loop. The distance of this apparent loop beyond the open hole is to be regarded as the correction due to the opening.

The result of the calculation for a number of positions is tabulated below :

Nos. of Positions (see p. 8-9)	λ 4	N
1	30.1	20.0
2	25.5	16.8
3	23.3	14.7
4	22.8	14.3
5	20.8	12.6
6	20.4	12.1
8	20.0	11.8
9	19.0	10.7
10	18.3	10.2
12	17.8	9.8
16	17.2	9.4
17	—	—
18	16.8	8.9
20	16.2	8.2
24	15.7	7.8
32	14.6	7.5

The fact that in the *syakuhati*, the change of the *interval* of the notes, but not the difference of the *number of vibrations* due to a given change in the embouchure, is nearly equal for different positions of the lateral openings, corresponds to the results of the experiment with the glass pipe viz., that the longer the air column, the steeper is the curve n to $\sigma^{\frac{1}{2}}$.

The results of the effects of lateral openings, if combined with those of the aperture of the embouchure, enable us to calculate approximately the pitches of the notes corresponding to different positions of the finger-holes.

Within the compass of the fundamental notes of the *syakuhati*, the correction due to the lateral openings, is represented nearly by

$$a = f(r) \left(\frac{d}{\lambda} + c \right),$$

where c is constant and $f(r)$ is a function of the radius r of the lateral openings. From the curve I in Fig. 7 for which the ratio $\frac{r}{R}$ is equal to that in the *syakuhati*,

$$a = 12.8 \times \left(\frac{d}{\lambda} + 0.047 \right) \text{cm.}$$

Again from Fig. 3, the correction due to the embouchure is given by

$$a' = A - m(n - n_0) = 10.8 - \frac{2}{250}(n - 250)$$

$$= 12.8 - \frac{272}{\lambda} = B - \frac{k}{\lambda}$$

now,
$$\frac{\lambda}{2} = l + a + a' = l + f(r) \left(\frac{d}{\lambda} + c \right) + B - \frac{k}{\lambda}$$

$$\therefore \lambda^2 - 2[l + cf(r) + B]\lambda - 2[f(r)d - k] = 0$$

$$\lambda = \{l + B + cf(r)\} \left\{ 1 + \sqrt{1 + \frac{2[f(r)(L-l-k)]}{[l + B + cf(r)]^2}} \right\}$$

In the *syakuhati*,

$$\lambda = (l + 13.4) \left[1 + \sqrt{1 + 2 \cdot \frac{357 - 12.8l}{(l + 13.4)^2}} \right]$$

For an example :—

Position	l	$\frac{\lambda}{2}$ calc.	$\frac{\lambda}{2}$ obs.
No. 9	23.4	37.7	37.7
No. 2	38.2	50.1	50.6

The variation of the sectional diameter of the pipe due to knots, is at most $1/20$ of the general diameter. For the fundamental tones of the different positions, the effects of such a small irregularity would be very small, as may be seen from the results of experiments on the effects of the diaphragm. The effect, however, increases when the irregularity becomes considerable in comparison with the wave length, since the inclination of the curves in Figs. 8, 9 and 10 becomes great with the decreasing wave length. This probably accounts for the change of the timbre due to the knots.

A direct experiment on the effect of a small change of the section was also made. Several glass tubes with equal lengths of 23 cm., and equal general sections of 2.2 cm., except at a place where they contracted or broadened by 1 or 2 mm., were attached to the embouchure of a cylindrical organ pipe. They were blown with a bellow under a constant pressure, which was measured by a water manometer. The frequencies of the different pipes were compared with a proper tuning fork by counting the number of beats. Whether the note of a pipe was higher or lower than that of the fork, could easily be decided by slightly varying the pressure of the air: if the increased pressure decreases the number of the beats, the pitch of the pipe is a little lower than that of the fork and *vice versa*. It was found that the effect of such a small irregularity is very

small, provided that it is not situated at the open end of the pipe. For the note c_1 , the variation of n was at most 3 when the above mentioned irregularity was situated at above 4 cm. from the open end.

The effect of the slight general conicality¹⁾ on the natural pitch, is known to be of a second order of magnitude.

The function of the *gorobusi* seems to be to lower the note for position No. 2, by increasing the resistance of the channel. If the knot is absent, the note will be a little too high and the interval of the note above the gravest note will be too great. Besides, it is suspected that the strength of the pipe due to this knot has something to do with the tone of the pipe. This is a question still to be studied.

The irregularity of the overtones remains to be explained. For most of the fundamental tones, the vibration of the air in the pipe is chiefly in the part of the pipe above the open hole nearest to the embouchure; the principal part of the energy of the vibration is transmitted to the external air from the lateral hole or holes. This is shown by inserting in the lower end of the pipe a glass tube communicating with a manometric capsule. The disturbance of the flame is very small compared with the case when the end of the glass tube is driven into the upper part of the pipe or when it is inserted in the lateral hole. However, when an overtone is excited which is higher than the octave of the corresponding fundamental note, the manometric flame communicating with the lower end of the pipe, is set in a forcible vibration, showing that for this mode, the lower part of

1) Rayleigh, Theory of Sound, II, 115.
Boutet, Ann. d. Chim. XXI, 150, 1870.
Blakley, Phil. Mag. VI, 119, 1878.

the pipe plays an important part in the production of the note. Indeed, for overtones, the distance between the lower end and the holes approaches the half wave lengths of the notes, so that the lower part may form a resonator whose pitch is near that of the upper part. Thus the pipe, as a whole, forms a communicating system of two resonators. The complete explanation of the phenomena may, therefore, be made only after the investigation of such a multiple system of resonators, has been fully made. However, a qualitative explanation is possible for a number of cases, as in the following.

In position No. 5, the virtual length of the pipe above the open hole is nearly equal to the whole wave length of the note $a_2^{\#}$ while the lower half is a little longer than the half wave length of the same note. Therefore, for this note, the vibration of the air takes place within the pipe in such a way that very near the open hole an actual loop is produced and only a small portion of the energy escapes from the lateral opening. This is verified by the experiment, since if the open hole be closed while the pipe is being blown, the general mode of the vibration remains nearly unaltered, only the pitch is slightly lowered. Indeed, $a_1^{\#}$ corresponds nearly to the second overtone of position No. 1. In a similar way, in the first overtones for the positions Nos. 18, 19, 20, 23, 24, 25, etc., the back hole approximately corresponds to the loop of the third overtone of the position No. 1. Therefore, for these positions in which holes near the nodes of that mode are closed, this note is liable to be produced.

In position 17, the fundamental tone is very high if compared with others such as Nos. 18, 19, etc. In this position, no energy escapes from the back hole, so that there is no change

in the note, if that hole be closed; the position is really equal to position No. 1.

The intermediate overtone f_2 in position 18, is related to the position No. 2, in the same way that No. 17 is to No. 1.

The intermediate overtone d_2+ is due to the lower half of the pipe.

The probable defect of the instrument, lies in the too wide interval of the notes between positions Nos. 1 and 2. This inconvenience may be avoided if an additional hole be opened below the *gorobusi*, corresponding to the little finger of the right hand. I have calculated the position of this side hole for the note d_1 , for the *syakuhati* investigated, and obtained 6.0 cm. for its distance from the open end. On opening the hole, the desired pitch was obtained, and moreover, the overtone of the new hole filled up the gap for the missing d_2^* . Another convenience attained by this hole is that, by opening it, the irregularity of the overtones is removed for most cases, since it divides up the lower part of the pipe into short halves and thereby hinders the interference due to that part. The best position of the new hole, however, must be determined rather by convenience in playing. From this point of view, a little higher position of the hole, would be recommendable, so that the end of the little finger might cover the hole without much effort.

My best thanks are due to Prof. A. Tanakadate and Prof. H. Nagaoka who have favoured me with kind encouragement and useful suggestions, during the course of my investigations, and also to Mr. R. Uehara who kindly placed his instrument at my disposal for photographic reproduction.

Fig. 1.



Fig. 2.



Syngnathus.

Fig. 1, Front view; Fig. 2, Back view.



Fig. 8.

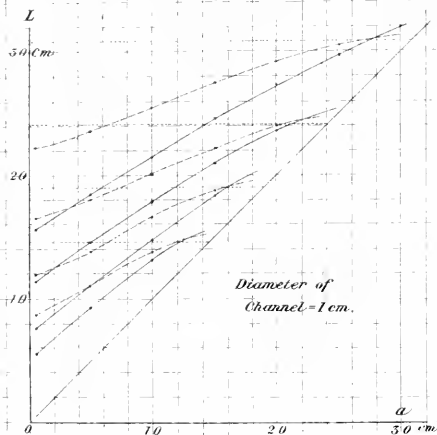


Fig. 10.

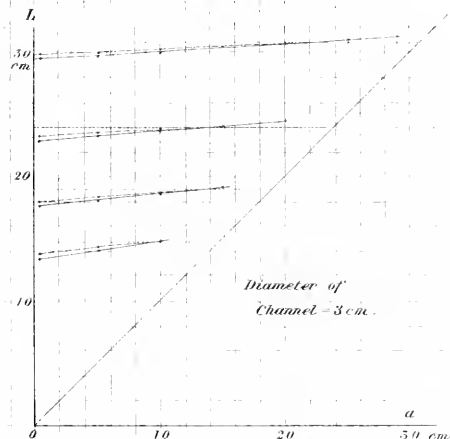


Fig. 9.

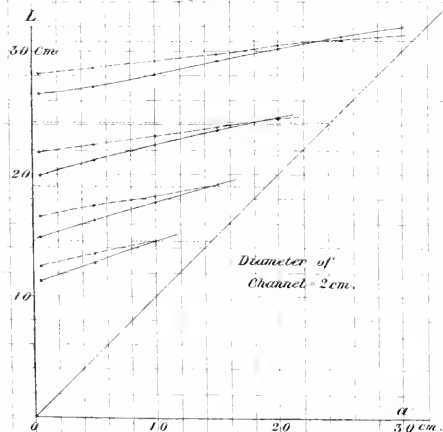
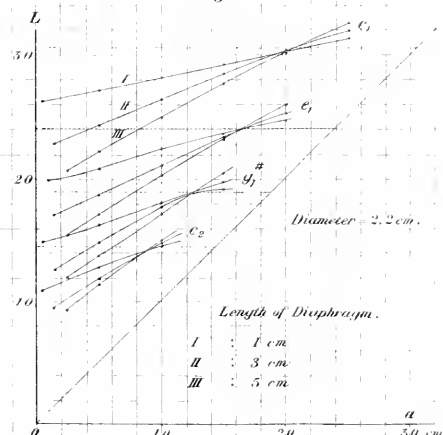


Fig. 11.







On the Gastrulation in *Petromyzon*.

By

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With Plates I.-III.

In a former paper,¹⁾ I dealt with the gastrulation of the ovum in *Petromyzon*, but owing chiefly to the want, at that time, of the living material at my hand, my sketch was necessarily incomplete. Since that time, I have had several opportunities to renew the observation; especially during the last spring, an unusually abundant supply of the material enabled me to carry on my work on this subject more satisfactorily than it had ever been possible. Unlike Tokyo, my former residence, there is in Sapporo a number of bodies of water in which the animal lives; it runs up in crowds rivers and brooks in and about the city to spawn in the sandy beds of these streams and also of springs. This circumstance induced me to try the artificial fertilization of ovum repeatedly, and I am glad to say the experiment was always attended with success. The material obtained in this way was sufficient for following the steps of changes undergone by the

1) On the Formation of the Germinal Layers in *Petromyzon*. Jour. Coll. Sc., Imp. Univ., Tokyo, Japan. Vol. V., Pt. I., 1891.

ova during gastrulation; and these steps are, so far as it seems to me, very peculiar but none the less interesting. I will describe, in the following pages, the chief points obtained.

Before passing to the explanation of the processes, it should specially be mentioned here that the ova in the earlier stages, from the blastula to the gastrula inclusive, are very liable to suffer artificial injuries caused by the effects of the killing reagents employed. At any rate, some unequal shrinkage is, in the stages in question, almost unavoidable: the animal hemisphere which is not only formed of a thin layer, but contains the hollow segmentation cavity, contracts necessarily more severely than the solid vegetative hemisphere, thereby causing not a little alteration in the shape of the ova. It is, therefore, advisable that the living material should be employed, at least, for the study of the superficial changes; and it follows that great care should also be taken in examination of sections for the preparation of which hardened ova are of course necessary. I have endeavoured to show such shrinkage in some of the figures given (*Figs. 17 and 21*), in which the ovum itself had considerably contracted causing strong wrinkles in the non-contractile chorion. It is probably from the same cause that hardened ova often deviate in configuration from the living.

For the sake of simplicity, I will start with what I have come to consider as the old morula stage given in *Fig. 1*. The ovum at this stage presents the shape of a sphere, the lower third of which shows a solid opaque appearance and represents the so-called vegetative or yolk hemisphere; while the upper larger part, the animal hemisphere, is more or less translucent containing the hollow segmentation cavity within. By stages, the ovum not only increases in bulk, but assumes the outline of a tall ellipse

(*Fig. 2*), the long axis of which passes through from pole to pole. The superficial area of the translucent hemisphere has been greatly added to since the last stage, while the opaque part has still further diminished in extent; it now occupies the lower fifth of the ovum, as will be seen from *Fig. 2*. To simplify description, the translucent hemisphere may be called the upper, and the opaque the lower, hemisphere.

This peculiar stage has been, so far as I am aware, entirely overlooked by all the previous authors. Max Schultze is the only author¹⁾ who figured correctly (*Fig. 15*, *Taf. I.*) the ovum of the stage in question, but he seems to have paid no special attention to this peculiar shape of the ovum and gives no account of it. The same omission was committed by the present author; *Fig. 1*, *Pl. I*, given by him in the above cited paper shows an oblique section through a little further advanced ovum in which the gastrula invagination is about to take place.

Now at a certain point in the line of junction²⁾ of the translucent hemisphere with the opaque, a shallow depression transverse to the long axis appears (*Figs. 3a and 3b, bg.*); this gradually extends itself to the right and left along the junction line, and at the same time it deepens, so that the depression, or as it may now be called the groove, is deepest in the part that appeared first and is shallowed out towards both its extremities. The deepest part in the middle represents, as further history will show, the dorsal side of the forthcoming creature.

The groove in question is not difficult to make out; the chorion which in the foregoing stages had been closely applied

1) Max Schultze: Die Entwicklungsgeschichte von *Petromyzon Planeri*. Haarlem, 1856.

2) This line will be called, in the following pages, the junction-line, denoting simply the boundary between the translucent and opaque parts of the ovum.

to the surface of the ovum, now stands apart at some distance from the latter. Seen from the lateral side, the ovum appears deeply constricted in the direction of the groove. For the sake of convenience this groove will be called the boundary groove from its position.

One might suppose that the groove just referred to represents an early trace of the blastopore, as was probably so assumed by Max Schultze.¹⁾ The present author came previously to the same erroneous assumption. The blastopore, however, appears later, as will become clear from the following description.

At a time when the arms of the groove nearly reach the opposite point of the ovum, a second depression (*Figs. 5a and 5b, bp.*) appears in the same meridional zone as, and a little below, the first one; *this constitutes the first rudiment of the blastopore.* The blastoporic depression is likewise transverse in position (*Figs. 5a, 5b, 6b, and 6c, bp.*); it is, however, not hollowed out evenly on the bottom in the shape of a pulley's groove, as in the case of the boundary groove (*Fig. 3a, bg.*), but is pushed forwards, so that in section the bottom presents an acute angle in the deepest part of the depression; thus producing dorsally a steep ridge overhanging the depression itself, while ventrally it is shallowed and loses itself on the surface of the opaque hemisphere. The whole of this crescentic groove appears like a nail-mark left on a soft body such as dough.

In the above statements I have set aside an important point which is, however, full of significance. Shortly after the appearance of the boundary groove, it is seen that the rounded base of the ovum, on which this rests in the position given in *Figs. 1, 2, &c.*, shows a more or less flattening of the surface near the

1) *loc. cit.* p. 13.

grooved part marked with \ast (*Figs. 4a* and *4b*), so that the ovum appears as if it were truncated at this part, as may be well seen in a lateral view. The field that lies between the groove and the flattened area of the base is gradually produced into an eminence which is soon converted into a cone with rounded tip (*Fig. 4a, c. em.*). The cone is directed not merely outwards, but also forwards, in extreme cases overhanging the groove in front like a beak, while laterally it slopes downwards to the right and left like a pair of wings (*Fig. 4b*).

Corresponding to the changes which have just been mentioned, the view from the lower pole of the ovum necessarily undergoes notable alterations. It is no longer circular in outline, but is pear-shaped being gradually narrowed towards the protruded (dorsal) part and coming to a point in that part as if it had been compressed from side to side, while the remaining (ventral) part is still rounded as before. The ventral rounded part still retains a spherical form, while the compressed part is, as just noticed, flattened. This flattened part of the basal surface remains, however, not long in this condition, but is gradually transformed into a slit-like depression (*Figs. 5a* and *5b, bp.*); it is this depression which was spoken above as an early trace of the blastopore. When the latter becomes obvious, the conical eminence grows for a time still more prominent (*Fig. 5a*), but subsequently it becomes depressed assuming a flattened out appearance (*Fig. 6a*).

According to my view, this series of occurrences is nothing else than the beginning of the gastrula invagination. As the lower opaque hemisphere begins to invaginate within the upper hemisphere, *i. e.*, to push on toward the opposite pole, it at first flattens instead of remaining convex as heretofore. The pushing inward is, however,

hindered by the mass lying within, and the inward pressure is thus converted into one directed against the part lying in front of and dorsal to it, the part thus pressed showing itself as the conical eminence (*Fig. 5a, c. em.*). When finally, the resistance to the inward movement is overcome, the flattened area moves further inwards towards the segmentation cavity as a continuation of the process of invagination and thus the blastoporic depression is finally established. When this is done, the conical eminence is at liberty to subside, becoming lower and flattened out.

It is further evident that the boundary groove is a product of the same process, though passive in origin: along the junction-line between the translucent and opaque halves, the thin wall of the translucent hemisphere is connected with the upper edge of the opaque half; and when the conical eminence is protruded, it is only the opaque part which takes part in this protruding. Thus, as the part below the junction-line protrudes while the part above it is kept distended by its liquid contents, and as the junction-line remains in its original position, there is necessarily produced a constriction along this line between the two parts; and this constriction is nothing but the boundary groove. Accordingly, the demarkation of the groove against the opaque part, which is at first faint, becomes sharp and distinct with growing elevation of the eminence. I have observed that at that time the groove appears to be brought nearer to the base (*Figs. 4a and 5a, bg.*) than before,—a phenomenon denoting the progressing invagination of the opaque hemisphere. The ventral view of the ovum remains as yet unaltered.

The appearance and subsequent disappearance of the conical eminence were doubtless observed by Max Schultze¹⁾,

1) *loc. cit.*, p. 7.

Calberla¹⁾ and A. Goette.²⁾ Goette regarded the eminence as the equivalent of the "Randwulst" of the Teleostean ovum and of the "Randzone" of the Amphibian ovum, while it seems not to have been understood by the two other authors at any rate. To a discussion on this point, I will return further on.

Let us now turn to follow the further fate of the two depressions above described, by which way the superficial changes of the gastrulation can be best learned.

In the first place, the history of the blastoporic depression will be dealt with. The limbs of the dorsal lip which overhangs the depression extend themselves further and ventrad along a level somewhat below the boundary groove above referred to, describing a large arc (*Figs. 7a and 7c, bp.*). The part of the ridge thus added likewise overhangs the depression at every part, but it becomes gradually lower towards both its distal extremities, finally to become lost on the general surface of the ovum.

This addition of the blastoporic lip in its extent is, however, brought about not by lateral prolongation of the blastoporic depression in its slit-like form, as might be supposed, but is produced by the opaque hemisphere generally sinking down in its proximal largest part. To do this, a small field of the hemisphere which lies immediately behind (ventral to) the slit is at first flattened (*Fig. 6c, bp.*); then, while the flattening is further extended into the ventral part, the flattened area is gradually changed into a large shallow depression which is deeper towards the median and the steepest part of the dorsal lip (*Fig. 7c, bp.*). In other words, the slit-like blastopore is now converted into the

1) E. Calberla: Zur Entwicklung des Medullarrohrs und der Chorda dorsalis der Teleostier und Petromyzonten. *Morphol. Jahrb.*, Bd. 3, 1877.

2) A. Goette: Entwicklungsgeschichte des Flussneunauges (*Petromyzon fluviatilis*). Hamburg und Leipzig, 1890.

the form of a widely gaping funnel, the dorsal part of which is wanting. The funnel formed would be entire if the opaque field were pressed down in the direction of the long axis of the ovum (cf. *Fig. 17*) ; but instead of that it is pushed dorsad and forwards, that is, in an oblique direction making an angle of some 60° with the axis (*Fig. 17, bp.*), so that a half-funnel is brought about. This sinking down of the opaque half is nothing but a part of an extended invagination of the lower hemisphere of the ovum.

The arc of the blastoporic lip attains its maximum extent in the stage when it describes about a semicircle (*Fig. 7c*). At this time the blastoporic funnel is represented by a large hollow excavation ; the hind part of the opaque hemisphere which is sickle-shaped in outline still shows a convex surface. From this stage on, both the limbs of the arc are brought nearer to each other ; *i. e.*, the angle contained in it grows less (*Fig. 8c, bp.*). And at the median deepest point of the funnel the blastoporic passage is converted into a circular pore. The convergence of the arc-limbs, however, goes on only until they assume the shape given in *Fig. 8c*, and stops long before the rest of the opaque hemisphere has all been changed into a concave surface ; and this shape of the blastopore is kept up until the entire withdrawal of the opaque part within the ovum. When this is nearly accomplished the blastopore shows a feature similar to that in earlier stages and is reduced into a small oval depression still wanting the ventral lip (*Fig. 10a*). The depression is then gradually converted into a circular pore (*Fig. 11b, bp.*) which constitutes the definitive blastopore.

This transformation of the oval depression into the circular pore is, as is very well seen in *Fig. 11*, brought about by the upheaval of the hitherto non-existent ventral margin of the blastopore. The ridge thus formed is nothing

else than the ventrally prolonged arms of the arched lips which had heretofore bounded the pore on the dorsal and lateral sides: the limbs have now become united at the median point of the ventral junction-line. In this way, the blastopore is for the first time surrounded all around by a lip. It should, however, be specially mentioned that the lip is in the ventral part very slight in elevation so that the general surface of the ovum still passes over into the floor of the invaginated pocket at a wide angle.

Now the gastrulation is completed; no trace of the opaque area can be detected on the external surface of the ovum. The ovum is much reduced in bulk, so that it is in size about two-thirds of that of the stage of *Fig. 2* and shows a solid, instead of a hollow, consistence.

It is a remarkable fact that the part of the opaque area which answers to the yolk-plug in the Amphibian ova is not represented here at any stage, as will be seen from the above accounts. A yolk-plug is present only when the invagination of the yolk field is delayed to a late stage in which the ventral lip of the blastopore is completely established, as is best seen in the Amphibian ova.

The process mentioned above was observed by Max Schultze, A. Shipley and A. Goette. Shipley states: "The invagination at first has a wide-arched slit-like opening, but this soon narrows into a small circular pore"¹⁾, but he says nothing further on this important part of the history; the sinking of the opaque hemisphere in the shape of a hollow funnel did not, it seems to me, attract his attention. Max Schultze²⁾ knew some of the changes

1) A. Shipley: On some Points in the Development of *Petromyzon fluviatilis*. Quart. Journ. Microsc. Sc., 1887, p. 5.

2) *loc. cit.* p. 13.

taking place in the opaque hemisphere; he gives, though briefly, an account of the depression of the lower hemisphere. Six of his figures (*Figs. 4-5a, Taf. II.*) show a close resemblance to those of the earlier stages of mine and at least attest his correct observation.

The accounts given by Goette are, on the other hand, more accurate; he says: "Diese (the first indication of the archenteron) besteht in einer queren, halbmondförmigen Furche, welche aufwärts gegen den Vorsprung oder die künftigen Rückenseite des Embryo durch eine wulstige Lippe begrenzt, deren seitliche Fortsetzungen aber nach unten gegen die spätere Bauchseite unmerklich verstreichen. Dies hängt zusammen, dass die Furche, indem sie sich taschenförmig vertieft, dabei die Richtung konzentrisch zu der oben gezeichneten Rückenfläche des Embryo einschlägt, also ventralwärts flach abläuft. Diese spaltförmige Tasche ist die Urdarmhöhle, ihre äussere Oeffnung das Prostoma"¹⁾. These lines are, it is obvious, to some extent in accordance with the statements given above by me concerning early stages. To my great regret, he gives no account of the further changes of the semilunar furrow which "ventralwärts flach abläuft," notwithstanding the fact that these changes represent, in my opinion, one of the most important points of the gastrulation, by which the *Petromyzon* ovum is put in sharp contrast to other ova of unequal-holoblastic segmentation, for instance, of the Anuran. First of all, the flattened yolk-hemisphere in *Petromyzon* is converted, towards later stages, into a deep and hollow depression, so that it is, as shown above, never brought into the form of a yolk-plug throughout the whole phase of gastrulation. This fact evidently shows a great activity of the opaque hemisphere itself, by which activity alone the invagi-

1) *loc. cit.*, p. 2.

nation is carried on. In the Anura, on the other hand, the yolk-hemisphere shows no indication of a depression on its surface at all and is exposed on the surface of the ovum down to a late stage until the gastrulation is completed; this exposed part of the yolk-field is what is called the yolk-plug. It is therefore plain that the invagination of the yolk-hemisphere is, in this case, not carried on by its own power alone, but is to a large extent effected by the sinking sickle-furrow, that is, by the infolding animal layer: in short, its own activity is almost *nil*. To this point, I will return further on.

In the second place, no less striking are the changes undergone by the boundary groove during the gastrulation. It was mentioned above that this groove becomes obvious for the first time at a certain point on the junction-line and gradually embraces the ovum (*Figs. 3a-4b, bg.*), constricting it into two unequal portions: the larger translucent and the smaller opaque. For a certain interval of time it does not, however, surround the ovum completely (*Figs. 5a-6b*); that part of the ovum just opposite the point of its first appearance remaining free from the constriction, although this part becomes likewise involved eventually (*Fig. 7a*). With the increasing growth of the conical eminence which, it will be remembered, appears below the boundary groove, the latter not only cuts in deeper, but is pushed forwards by the eminence to cause in its middle portion a curvature with the convexity turned toward the front: in other words, the boundary groove retains no longer its original transverse position. Towards the ventral part, the groove becomes shallow passing over into the junction-line which in this part still remains in the original condition (*Figs. 4a and 4b, bg.*). As the visible blastopore appears and consequently the

conical eminence decreases in height, the groove grows further in curvature, for it is pushed forwards on the dorsal surface of the ovum by the eminence now flattened in consequence of withdrawal of the cells composing it. As the invagination goes further, the elevation increases in its antero-posterior extent, pushing the groove still further forwards. The eminence may now be called the embryonic shield (*Figs. 6a, and 6b, em.s.*). By the time when the invagination has extended over the larger part of the vegetative field (*Fig. 7c.*), the ovum is completely surrounded by the groove, although still shallow in the ventral part just constricted (*Fig. 7a, bg.*).

The translucent part of the ovum, against which the remaining parts are marked off by the groove, is in the course of development, continually diminishing in extent, and at a stage like that represented in *Figs. 8a and 8b*, it is reduced into a small swelling, while the embryonic shield has extended considerably. This reduction of one part and the augmentation of the other are, in early stages, evidently the effects of one and the same process, *i. e.*, of the invagination, by which the segmentation cavity is partially obliterated; but in later stages, the matter is much complicated, as will be explained in the following lines.

I will here call attention to the change of the position of the groove in the stages spoken of. A comparison of the groove in *Fig. 7a* with that in *Fig. 8a* shows an apparent forward shifting of it, *i. e.*, an extension of the embryonic shield (*em.s.*). If this shifting of the groove were done, as in early stages, merely by the sinking down of the opaque hemisphere from the surface, it ought necessarily follow that the junction-line at the ventral median line (indicated with **) would have much

approached the dorsal blastoporic lip, since in order to add such a considerable extent to the embryonic shield, a great deal of the opaque hemisphere must invaginate within the ovum. But as seen in the figures referred to, this hemisphere in fact suffers but little change of extent, except that it is more or less depressed on the surface. We are thus led to conclude that the marked translocation of the groove is mainly brought about by the extension of the embryonic shield produced by the *backward shifting of the translucent animal layer*. The opaque hemisphere has only little, if at all, to do with the invagination or with the reduction of the segmentation cavity. Thus, it is obvious that the marked translocation of the groove is an apparent one: its real shifting due to the actual invagination of the opaque hemisphere is probably very little. As will be shown further on, this translucent layer, shifting backwards, partly contributes to the growth of the blastoporic lip and is partly turned inwards.

In this way, the translucent part containing the segmentation cavity, is, in a still further advanced stage, reduced into a small vesicle and comes to be situated somewhat in the ventral aspect of the ovum (*Figs. 9a*); the boundary groove around it is accordingly seen also on the ventral aspect. Finally with the thorough obliteration of the segmentation cavity, the groove is, of course, lost from sight (*Fig. 10a*). Now the ovum assumes a new outline; it is swollen in the anterior part and decreases in bulk posteriorly, while, in a little younger stage, it is rather bigger in the posterior part with the ventral part of the yolk-hemisphere still bulging out (*Fig. 9a*). The ovum is now pear-shaped (*Fig. 10a*).

Standing thus in intimate connection with the gastrula invagination, the boundary groove marks precisely the extent in

which the process goes on: every part of it is pronounced on the external surface of the ovum.

The previous authors give no account at all of the groove just dealt with. Max Schultze only touches on it¹⁾; however, he ascribes to it, as above referred to, quite another meaning, regarding it as the earliest indication of the blastopore. Prof. Ch. Ishikawa discovered, independently from myself, the groove in the Japanese Giant Salamander (*Megalobatrachus maximus*), of which an account of the early development was published last summer.²⁾

I will finally give a brief explanation of the changes of the conical eminence which has been touched upon incidentally. The conical eminence is at first brought about by the commencing invagination of the opaque hemisphere, and in the course of the process, it is extended and flattened into the embryonic shield which is anteriorly and laterally bounded by the boundary groove (*Figs. 5a-8b*). The embryonic shield comes later to be produced in front into a conical knob from the upper end of the ovum, when the translucent swelling containing a small remnant of the segmentation cavity has been driven into the ventral aspect (*Figs. 9a and 9b*). When this swelling at last disappears from the ovum and the ovum assumes a pear-shape, a prominent elevation of an oval outline becomes obvious on the dorsal surface of it; it is rounded and broad in the anterior part and is gradually narrowed towards the blastopore to become lost in the neighbourhood of the lateral blastoporic lips (*Fig. 10, m.p.*). This elevation is doubtless the medullary plate which answers

1) *loc. cit.* p. 13.

2) Ch. Ishikawa: Gastrulation of the Japanese Giant Salamander (*Megalobatrachus maximus*). Zool. Magaz., Vol. XVII, 1905.

to the corresponding structure, for instance, in Amphibian ova. A narrow but sharply defined groove (*Fig. 10 b, r.r.*) running lengthwise along the median line of this oval field represents the "Rückenrinne." It is broader and deeper towards the blastopore and communicates with it (*Figs. 10 b and 10 c, r.r.*), while anteriorly it fades away.

The gastrulation in the present condition is not yet closed, but has yet to envelope the opaque hemisphere which is still exposed between the blastopore and the boundary groove that has just disappeared. This exposed part is brought within to some extent, doubtless by the active invagination of the opaque field itself, which has been uninterruptedly taking place from the first: it is flattened and depressed in the like manner as in the preceding stages. An active growth of the dorsal blastoporic lip is, however, indisputable from the fact that the medullary plate is obviously added by stages in its antero-posterior length. This addition in the plate is indeed not less than one-third of the original length, by the time a prominent pair of the medullary ridges becomes visible (compare *Figs. 10 a and 10 b* with *Figs. 11 a and 11 b*). Such an enormous growth of the blastoporic lip denotes nothing else than its overgrowth on the opaque field, which accomplishes, under co-operation of the invagination of the opaque field itself, the process of gastrulation. Now the blastopore assumes a circular outline; the precise mode by which the pore is brought into the definitive form has already been stated in foregoing pages.

I will now turn to follow the internal changes corresponding to the superficial occurrences described in the preceding pages. Let us start again from a young blastula stage. *Fig. 12* shows

a vertical section through the two poles of the blastula which is still spherical in outline. The segmentation cavity (*s.c.*) which is semilunar in shape occupies the upper half of the ovum; the cavity is roofed by a dome-like layer, while its floor is formed by a thick mass of cells. The cupola part (*a.h.*) is the animal hemisphere which looks translucent, when observed as an opaque object, because it is thin, consisting of a layer only 2-3 cells in thickness; these cells are smaller than those which compose the remaining part of the ovum, the vegetative hemisphere (*v.h.*). The smaller cells, the micromeres or animal cells as they are called, can further be distinguished from the larger cells by their smaller nuclei and by the smaller quantity of yolk-granules which they contain. The macromeres, which contain larger nuclei, are loaded with an enormous quantity of yolk.¹⁾

The segmentation cavity is not bordered by a sharp limit; the cells in both the animal and vegetative hemispheres project, or even are set free, into the cavity: in this stage, the cells of both kinds are evidently still undergoing segmentation.

In the vertical section (*Fig. 13*) through the axial plane of the ellipsoidal ovum (cf. *Fig. 2*), the segmentation cavity (*s.c.*) shows conspicuous changes; it is no longer semilunar, but circular in outline; and it now occupies the upper four-fifths of the ovum. The micromeric wall (*micm.*) forming the animal hemisphere is still represented by a layer which is 2-3 cells thick; the vegetative hemisphere is, on the other hand, formed as before of

1) B. Lwoff (Ueber die Bildung der primären Keimblätter etc. bei den Wirbeltieren. Bull. Soc. Natural. Moscou, 1894) informs that the yolk-granules contained in the macromeres are coarser than those in the micromeres, a distinction which I can not make out in spite of careful observations.

a thick crowd of macromeres (*mac.m.*), although this has much decreased in thickness as compared with the corresponding part in the foregoing stage. Moreover, the inner zone of the layer is no longer loose in structure, but is very compact. The same is also true of the micromeric layer. Consequently, the demarkation against the segmentation cavity is no longer an irregular line, but is even and sharp. We may therefore say that here the segmentation is over and that the ovum is fully grown in the axial diameter by multiplication of the component cells.

It should be further noticed that the floor of the segmentation cavity is not flat, but is excavated, so that the massive layer of the floor and the thinner eupola layer pass over gradually, not abruptly, into each other. The animal hemisphere is fully distended; the distension seems to be maintained by a more or less viscous fluid of albuminous nature, which fills up the segmentation cavity and which coagulates when hardened and is affected, though faintly, by staining reagents.

A median sagittal section through an ovum, in which the boundary groove is just manifest, is represented in *Fig.* 14. A change which draws attention first of all is a shallow indentation formed at the junction of the micromeric layer with the macromeric (*b.g.*); this is the boundary groove cut through. No less conspicuous is another change met with in a small area of the micromeric wall (*mic.ep.*), which forms the upper half of the groove. Here it is thinned out, being reduced into a layer one cell deep, while the remaining parts are still in the same condition as before: so that the transition of these parts is no longer gradual but abrupt, the micromeric layer one cell thick passing at once into the multicellular macromeric wall (*Figs.* 14 and 23). The micromeric layer under notice is not an aggregation of indifferent cells

as in a younger ovum, as will be seen by a comparison of this part with the corresponding part in the ovum last described (*Fig. 13*), but it constitutes a typical columnar epithelium which stands in direct connection with the indifferent mass of yolk-cells. While the micromeric layer is in this way undergoing histological differentiation, the macromeric part also does not remain unchanged; it is produced by cell-multiplication outwards into a rounded elevation (*c. em.*), which represents the forerunner of what I have called above the conical eminence.

The origin of the boundary groove has already been explained and is not difficult to understand. Notwithstanding the eminence protruded, the junction line, *i. e.*, the connection of the epithelium with the solid mass of yolk-cells, retains its original position, while the thin-walled animal hemisphere above this line is kept distended by pressure of liquid contents within it. Consequently, a constriction or a groove is necessarily brought about along the junction line as a passive result; this is the boundary groove (*Fig. 14, b. g.*)

The boundary groove is very striking in the median sagittal section through a little further advanced ovum (*Fig. 15, b. g.*), in which a dorsal small part (***) of the vegetative hemisphere is flattened. In this section it is very well seen that the groove looks striking, not because it had sunk deeper, but merely because of the further protrusion of the eminence (*c. em.*), which now shows a conical configuration when observed as an opaque object (see *Figs. 4a* and *4b*). In sections of the same stage (*Fig. 15*) it is seen that the cells composing the eminence and the flattened part are much smaller and more thickly crowded than those of the remaining part of the macromeric hemisphere (this point is unfortunately not well shown in the figure). Further, a part of the macromeric

mass lying close to the boundary groove has slipped a little into the segmentation cavity, as may be gathered by comparing the points marked with \otimes in *Figs.* 14 and 15. From these facts it is not difficult to infer that the component cells in this part, especially in the inner zone, have been undergoing repeated division. This increase in bulk of the inner mass must be one of the causes of the upheaval of the conical eminence.

Notwithstanding that there is detected as yet no trace of an indentation which represents the commencing depression of the blastopore, the flattening of the macromeric hemisphere can safely be regarded as the first step of gastrula invagination (p. 3).

The relations of these parts are made still clearer in the section through the median sagittal plane of a little older ovum (*Fig.* 16) in which the blastopore had come into view in the form of a nail-mark (compare with *Figs.* 5*a* and 5*b*). The flattened area of the vegetative hemisphere is converted into a large notch (*bp.*): this notch represents evidently the earliest trace of the visible blastopore. I wish to explain in the following lines the mode by which the notch is brought about, the position where it appears and the effects which are imparted by the formation of it to other parts. In the first place there is little room for doubt that the notch is formed not passively by downward pushing of the conical eminence (*c.em.*), but by a gradual infolding of the flattened field, which infolding is carried on by its own activity and is the continuation of the process that caused the flattening. The pushing in of the macromeric mass of this part forms a large fold raised into the segmentation cavity; and the component cells which in younger stages formed the superficial row of the flat field now take a radial arrangement.

It follows, in the second place, that the blastoporic notch

appears *not at the junction line, i. e., not at the boundary between the micromeric epithelium and the macromeric cell-mass, but in the macromeric part itself*. In younger stages (*Fig. 14*), the upper limit of the conical eminence is represented by the boundary groove which there coincides with the junction line. When the curvature of the boundary groove takes place (*p. 11*), the groove in the dorsal part shifts a little further forwards; nevertheless, the conical eminence is formed almost entirely of the macromeric part (*Fig. 15*). Therefore, decidedly macromeric must be the flat field which forms the lower slope of the eminence; and it is this field which is converted into the blastoporic notch (*Fig. 16*). The junction-line corresponds, in the stage spoken of (*Fig. 16*), to the free margin of the dorsal blastoporic lip(^{*)}, as it may now be called; this line is, however, by no means distinct nor sharply defined.

Lastly, as an effect of the actual (visible) invagination of the macromeric part, the segmentation cavity is obliterated to a certain extent and consequently assumes a new outline (*Fig. 16. s. c.*). The conical eminence suffers a greater alteration: it is changed into a less conspicuous elevation which lies between the blastopore and the boundary groove, its original conspicuous part having been pushed in, forming the walls of the invagination. The boundary groove (*b. g.*) which has become, as stated above, manifest by the growing prominence of the eminence, becomes likewise inconspicuous. It is no doubt these changes which caused Goette to state: “Sie (the eminence) verstreicht aber sehr bald, nachdem gerade unter ihr, also zwischen dem Rande der Keimhöhle und dem Gegenpol, die erste Andeutung des Urdarmes sichtbar geworden ist.”¹⁾ I can not but wonder at his keen

1) *loc. cit.*, p. 2.

insight which is expressed in this short account; indeed, he correctly observed the position at which the blastopore becomes first visible. According to him, it is found "zwischen dem Rande der Keimhöhle und dem Gegenpol," while all other investigators maintain that the pore occurs at the boundary between the micromeric and the macromeric part, *i. e.*, at the junction-line itself. This part—the part of the first appearance of the blastopore—is, however, not regarded by Goette, as I do, as a macromeric part, but as a micromeric; for, according to him, the conical eminence is brought about by "Anhäufung der dort scheinbar entstehenden und hinabrückenden Mikromeren,"¹⁾ and the blastoporic cavity is nothing else than a fissure appearing in this cell-mass. Starting from this standpoint, he assumes that the whole process of gastrulation consists in two processes: *a*) the backward shifting of the micromeric layer roofing the segmentation cavity and the forward pushing of the layer forming the archenteric roof, which both represent his so-called "dorsale Einstülpung," and *b*) "Umwachsung der Makromeren durch die Mikromeren." The process which brings forth the "Anhäufung" of the micromeres represents, according to Goette, this backward shifting of the micromeric roof of the segmentation cavity. This assumption is, I believe, not in accordance with the facts, and the point of dispute lies after all in the origin of the cells giving rise to the "Anhäufung" or the conical eminence.

There are several facts which make us infer their being macromeric in origin. First of all, these cells are loaded with thickly-crowded yolk-granules and contain large nuclei, so that they can not be distinguished, in these respects, from those in

1) *loc. cit.*, p. 4.

other macromeric parts occupying the largest ventral portion of the ovum (see *Fig. 23*). While these characteristics disappear rather abruptly in the micromeres forming the columnar epithelium, there is ventrally, in this respect, never any distinction between this mass of cells and the remaining macromeric part. In addition to this, there occur active cell multiplication, —a fact which shows that the cells are not derived from other parts, but are formed here. Compare *Fig. 14* with *Fig. 15*. Notwithstanding the fact that the eminence has grown much more conspicuously in the latter section than in the former, there can be detected no indication of downward shifting of any cellular elements which may contribute to the growth of the eminence. After all, it is plain that the cells forming the conical eminence are the macromeres which have here multiplied *in situ*, not “scheinbar” but in reality.

Having made out the early steps of the gastrula invagination and the relations to the parts with which it stands in connection, I will turn to the explanation of further changes going on in different parts: the changes in reference to *a*) the differentiation of the micromeric elements forming the roof of the segmentation cavity, *b*) the invagination of the macromeric and micromeric parts, and *c*) the translocation of the boundary groove and the obliteration of the segmentation cavity in consequence of the progressing invagination.

a) The epithelial structure of the micromeric layer, which is in early stages confined to a small area, is by stages extended farther and farther (*Figs. 16–22*). Already at a stage when the segmentation cavity is reduced into a small vesicle (*Figs. 8a* and *8b*), the differentiation almost reaches, at least on the dorsal median part, the entire roof of the segmentation cavity (*Fig. 19*).

In an ovum with ventrally shifted segmentation cavity (*Figs. 9a* and *9b*), the median sagittal section of which is represented in *Fig. 20*, the micromeric layer assumes epithelial character throughout and is at its ventral limit (§) sharply marked off against the macromeric part, just like its dorsal limit at the stage when the invagination was about to take place (*Figs. 14* and *23*).

Laterally the differentiation proceeds in a similar way as in the median zone just stated, as will very well be seen in the three sections represented in *Figs. 25, 26* and *27*. Of these three figures, the last (*Fig. 27*) is a transverse section through an ovum a little younger than that shown in *Fig. 8a* or *Fig. 19*; the lower depressed part (*bp.*) shows a part of the blastoporic funnel; on either side of the macromeric cell-mass, we see very well its connection with the micromeric layer which presents the typical character of a columnar epithelium. The two other figures (*Figs. 25* and *26*) were drawn from a series of horizontal longitudinal sections through an ovum of about the same age as that shown in *Figs. 7a* and *7b* or in *Fig. 18*. In the section taken from the dorsal part (*Fig. 25*), the differentiation of the animal layer already reaches the junction-line, while in the other section (*Fig. 26*) from the ventral part, the layer is still many cells in thickness.

Great care was taken to make out in every possible way the actual mode by which the aggregated elements of the micromeric layer are brought into the epithelial structure; but all my efforts have been fruitless after all. Although wanting positive evidence, we can make some surmises from another point of view. There can be only two possible modes: either the outermost cell-row of the indifferent animal layer comes to be converted *in situ* into

the definitive epithelium, or the indifferent cells wedge in between other cells so as to produce an epithelial layer one cell thick. If the former mode were the case, the cells of the inner rows must either fall into the segmentation cavity, or shift downwards along the inner surface of the outermost row, becoming heaped up, as it were, at the foot of the animal layer. In reality, there are never and nowhere detected such indications. On the contrary, in the part where differentiation is going on, the cells of the outer row and those of the inner rows are found pushing in between one another, and the layer of such condition passes over gradually into the part which has already become a true epithelium (*Figs. 14–19 and Fig. 23*). The latter supposition seems, therefore, to be in accordance with facts. And this is reasonable, since the animal layer has to extend exceedingly in order to invest completely the macromeric hemisphere, *i. e.*, to accomplish gastrulation, as will be shown in future pages.

b) As regards the invagination, a part of the flattened macromeric field which is still seen projecting from the surface below the blastopore (*Fig. 16*, †) comes first under notice. In a little further advanced ovum (*Fig. 17*), this part is lost from sight; the invagination, on the other hand, goes deeper. The invaginating pocket is not turned towards the center of the segmentation cavity as in younger ova (*Fig. 16*), but pushes its way dorsad and forwards under withdrawal of the protruded part which at first is in the floor of the pocket but must sooner or later lie in the roof (*Fig. 17*). The dorsal wall of the blastoporic pocket is consequently brought to involve the macromeric field, and here the archenteron (*ar. en.*) is formed for the first time. It is therefore plain that this additional invagination (*Fig. 17*) is made entirely by the cells which formed

the projected part. Now it follows that the cells composing the roof of the archenteric pocket first formed are those which formerly gave rise to the conical eminence, while its floor is represented by the macromeric mass which had lain ventral to the eminence.

The layer constituting the archenteric roof shows an epithelial character (*Figs. 17 and 18, mac. ep.*); it is, however, not difficult to distinguish from the regular cylindrical epithelium of the outer layer. It looks irregular because it is composed of tall cells which are variable in shape and length and are thickly loaded with yolk-granules; further it is distinguished by the nuclei of the cells being larger than those of the outer layer cells. The outer regular and the inner irregular epithelium pass over into each other at the dorsal lip of the blastopore. On the other hand, the inner layer is to be traced uninterruptedly into the outermost row of the macromeres, which is partly invaginated but is in the greater part still exposed. The irregular epithelium arises without doubt by delamination, so to speak, from the subjacent cells. The row of cells forming the floor of the segmentation cavity has nothing to do with the epithelial layer in question; it always shows its original sharp contour. On the contrary, in front of the anterior end of the invaginating pocket, there is always seen some disturbance of cells, and some detached cells are seen projecting into the segmentation cavity (*Figs. 17-19, ** and Figs. 25 and 26, ***). This appearance is due, it seems to me, merely to the fact that here the outermost row of macromeres is being split off from the underlying crowd of cells, to be turned into the archenteric roof.

Passing now to a little further advanced ovum (*Fig. 19*), the

roof of the archenteron is no longer formed of the irregular epithelium of macromeric origin (*mac. ep.*) alone, but a regular columnar epithelium (*i. mic. ep.*) is added to form the posterior section of it. The latter part is not only similar in every histological respect to the outer epithelium (*Fig. 24 c. mic. ep.*), but is directly continuous with it at the dorsal margin of the blastoporic aperture. No doubt both have the same micromeric origin. The anterior limit of the inner micromeric epithelium (*Fig. 19, **) against the macromeric epithelium is by no means distinct, but both the layers gradually pass over from one to the other. Traced towards the lateral part, the micromeric epithelium forming the archenteric roof gradually decreases in its antero-posterior extent, finally to get lost at the blastoporic margin still represented by the junction line. Therefore, the micromeric roof is at present posteriorly limited by a crescentic outline.

The contribution of the micromeric layer to the formation of the archenteric roof has already been pointed out by Balfour¹⁾; but it was more clearly made known by Goette²⁾ and Lwoff.³⁾ Goette's view differs, however, from the accounts given above by me in so far as concern the origin and the extent of the layer. Goette's assumption of the gastrulation, which Lwoff confirms, attributes micromeric origin to the archenteric roof in its whole extent, while according to the results of my present work, the anterior part of the roof is represented by macromeric layer. At any rate, so long as the blastoporic lip extends in the form of a large arc (*Figs. 5b, 6c, and 7c*), the archenteric roof is formed entirely of the irregular macromeric epithelium

1) Balfour: *Comparative Embryology*, vol. II, p. 85. A. Shipley gives a brief account of the same fact (*loc. cit.*, p. 5).

2) *loc. cit.*

3) *loc. cit.*

alone (*Figs.* 16-18, *mac. ep.*); it is probably this part of the epithelium, which misled Goette and Lwoff to assume the archenteric roof as being, in its entire extent, formed of an irregular epithelium 1-2 cells in thickness. As soon as the limbs of the are commence to come nearer each other (*Fig.* 8c), the micromeric epithelium appears inside in the archenteric roof (*Fig.* 19); it is thus supposable that the approximation of the are-limbs, *i. e.*, of the lateral blastoporic lips, stands in an intimate connection with the contribution of the micromeric epithelium to the formation of the archenteric roof, as the following consideration will show.

With the commencing infolding of the micromeric epithelium, the blastoporic lip is strongly raised in its median part (*Fig.* 8c), and the slit-like passage of the blastopore is converted at this part into a circular pore. This circumstance is brought about by the complete withdrawal within of the macromeres in this part and by the subsequent lifting of the blastoporic lip formed of the micromeric epithelium which is now being invaginated. For illustration of this point, the three figures, *Figs.* 27-29, are instructive: they were drawn from a series of sections through an ovum a little younger than that shown in *Fig.* 8a or *Fig.* 19 and represent cross-sections passing respectively across the ventral part (*Fig.* 27), the blastoporic passage (*Fig.* 28) and the dorsal lip of the blastopore (*Fig.* 29). In the first figure (*Fig.* 27), the micromeric layer (*e. mic. ep.*) is not yet turned inwards, though the invagination of the macromeres has proceeded to a great extent (*bp.*). In the next figure (*Fig.* 28), the macromeric field is no longer exposed on the external surface of the ovum, but has retired far inside; and the blastoporic passage is bordered, from right and left, by the lateral walls formed of

the infolding micromeric epithelium (*e. mic. ep.*). In the third figure (*Fig. 29*), the already infolded epithelium forms the median part of the archenteric roof (*i. mic. ep.*) which is obliquely cut through. It is therefore obvious that so long as the macromeric field is exposed on the external surface, the blastoporic lips on the lateral sides, *i. e.*, on the limbs of the arc, stand apart from each other; when the macromeric half is entirely withdrawn inside and the infolding of the micromeric epithelium commences its work, the lips are brought nearer: hence results the change of shape in the blastoporic arc. I should here add that neither the micromeric nor the macromeric part is passive in the process, but both are in active state. The infolding of the former is, of course, carried on by its own activity, *i. e.*, by extension of the layer in general, which is brought about by both the cell-multiplication of the epithelial components and the dovetail-insertion of the micromeres forming the cupola of the segmentation cavity. The invagination of the macromeres is likewise actively taking place; this is in fact the same active process as that which more early caused the blastoporic depression.

At the stage of *Fig. 19* there is already comparatively little cell disturbance in front of the archenteron (*Fig. 19, ::*). This shows that the delamination of the outermost cell-layer of the macromeric mass to form the archenteric roof is of a short duration and of a limited extent. On the other hand, there is a strong reason, as briefly stated on p. 13, for believing that the backward shifting of the outer micromeric layer (*Fig. 19, e. mic. ep.*), at the cost of which the formation of the archenteric roof is accomplished, is of a greater importance. This shifting seems to be more active in later stages (*Figs. 20, 21, and 24, i. mic.*

op.), in which the larger part of the archenteric roof is already occupied by the micromeric layer. In the stage of an ovum represented in *Fig.* 21, the anterior end of the archenteron has pushed its way across the segmentation cavity and has struck against the ventral part of the peristomal mesoderm which is brought forth from the ventral junction line destined to be transformed into the ventral lip of the blastopore.

The mitosis met with very frequently in the outer micromeric layer (*Figs.* 19-21 and *Figs.* 27-30) has naturally no other significance than an active growth of the layer, by which not only the outer layer itself but also the archenteric roof is extended.

At the stage shown in *Fig.* 21, however, a large part of the macromeric hemisphere is still exposed. This part invaginates, as before, by its own activity as shown by the depression on the surface; but in order to bring forth the complete gastrula, this part is doubtless overgrown to a great extent by the dorsal and lateral blastoporic lips now formed of the micromeric epithelium. The overgrowth is, however, certainly brought about, not by a free growth of the lips' rim as it were, but by the outer micromeric epithelium itself which is shifting backwards uninterruptedly from earlier stages and is extended by the active superficial growth mentioned above. This layer of course migrates inwards about the blastoporic lips, but, at the same time, it narrows the blastoporic aperture, causing the lips to grow on in such a manner that the blastopore is ultimately converted into the definitive circular form (*Fig.* 22).

From the above observations, we see that the micromeric epithelium is brought into the archenteric roof by its infolding and that it overgrows a large part of the macromeric hemisphere

by its backward shifting and superficial extension. In consequence of these processes, the large arched blastopore suffers changes in its shape and ultimately acquires the definitive form. After all, the whole occurrences are nothing else than those which answer to the overgrowth of the animal layer over the large blastopore in *Amphioxus* in which it takes place only after complete invagination of the vegetative hemisphere, while here in *Petromyzon* earlier phases of the overgrowth overlap to some extent later phases of the invagination. At any rate, it is true that some later phases of the gastrulation in *Petromyzon* as well as in *Amphioxus*, consist entirely in overgrowth of the micromeric epithelium.

The invaginated micromeric epithelium is not of a great breadth from side to side; however, it occupies completely the roof of the archenteron which presents, on cross-sections, a small lentiform shape, while the lateral walls and the floor of the cavity are formed by the macromeric cell-group (*Figs.* 24 and 29). It is plain that this relation of the micromeric epithelium to other parts has been brought about in such a way that the macromeric epithelium (folded at the blastoporic lip) partly migrated inwards and partly caused the lip to grow farther backwards, while the depressed macromeric surface was deeply withdrawn leaving a concavity on the surface. The archenteric cavity is accordingly represented by the depressed or grooved surface of the macromeric hemisphere itself (compare *Fig.* 29 with *Fig.* 28). It is this part of the micromeric epithelium which is called by Lwoff¹⁾ the "Dorsalplatte." It must be remarked here that the boundary between the micromeric "dorsal plate" and the macromeric lateral walls and floor however does not correspond to the

1) *loc. cit.*

junction line: a number of the macromeric elements at this part on either side is pressed out of the archenteric border, and a new connection is established between the micromeric epithelium and the macromeric part. Such a particular process is perhaps indispensable, because a broad surface of the macromeric hemisphere is converted into a narrow passage of the blastopore. The cells thus pushed out assume a looser epithelial arrangement which stands on both sides in connection with the "dorsal plate," as if they were its lateral continuations (*Figs. 27-30, l. mac. ep.*). It is this structure which much attracted the attention of observers and misled especially W. Scott¹⁾ to assume it as the mesoderm split off from the main mass of the macromeric elements. For the convenience of reference, I will call it the lateral irregular epithelium, although it is by no means to be regarded as a definite structure.

Anteriorly the "dorsal plate" is more or less broad and passes over into an irregular epithelium of the archenteric wall brought about by early invagination of the macromeric elements. At its posterior extremity, the "dorsal plate" is divided at every stage after its appearance into two arms which embrace the blastopore from the dorsal side forming its lateral lips (*Fig. 28*). In the complete gastrula, the lateral lips represented by the folding of micromeric epithelium are extended to the ventral median part, the two arms meeting with each other at the ventral blastopore lip; but the folding in is here still very slight (*Fig. 22*). After all, the oval depression of the blastopore is for the first time converted into a circular pore which constitutes the definitive blastopore.

1) W. Scott: Beiträge zur Entwicklungsgeschichte der Petromyzonten. *Morphol. Jahrb.*, Bd. VII, 1882.

It is a remarkable fact that a part of the macromeric cell-mass, known as the yolk-plug in Amphibian ova, does not come into view at all. As before noted (p. 11), the yolk-plug is, in fact, a part of the vegetative hemisphere, which is still exposed after having already been surrounded by the furrow of the sickle-groove brought about by infolding of the animal layer. In the *Petromyzon* ovum, there is never an occasion for such a temporary phenomenon to manifest itself, because the definitive ventral lip of the blastopore is wanting in the younger stages and is found only in the complete gastrula.

A wedge-shaped structure composed of small cells and found immediately inside the ventral blastoporic lip in the gastrula (*Fig. 22, p.m.*), represents the ventral part of the peristomal mesoderm, which when traced anteriorly, is continuous to the gastral part of the mesoderm already formed in this stage on both sides of the "dorsal plate." It is proliferated out of the micromeric epithelium forming the blastoporic lips. Earliest traces of the proliferation is seen already in a little younger ova (*Fig. 23, p. m.*).

We have therefore before us archenteric walls, in which the "dorsal plate" makes up the larger posterior section of the roof of the cavity and in which the anterior part of the roof is formed of the macromeric epithelium, while the lateral walls and the floor are represented by indifferent macromeres. The "dorsal plate" gives rise, in its median part, to the gastral mesoderm (*Fig. 24, g. m.*), and in the blastoporic lips, to the peristomal mesoderm. The irregular macromeric epithelium forming the anterior archenteric wall loses gradually its epithelial structure and together with the lateral irregular epithelium, becomes indistinguishable from other macromeres; consequently

the archenteric cavity in this part, though visible for some time here and there as irregular spaces, is finally lost from sight (*Fig. 22*).

c) Passing now to the translocation of the boundary groove and obliteration of the segmentation cavity, I have left the history of the boundary groove at a stage when the visible blastopore appears for the first time (*Fig. 16*). Thenceforth the groove shifts farther and farther forwards, as the archenteric pocket is added in length, to some extent by inward migration of the micromeric epithelium, but largely by invagination of the macromeric hemisphere, which process reduces the segmentation cavity (*Figs. 17-19*). It is thus plain that the forward shifting of the groove indicates the extent into which the segmentation cavity is obliterated. It must however be borne in mind that the ovum soon arrives at a stage, in which side by side with the active invagination of the macromeric hemisphere there is going on another process, viz., the backward shifting of the outer micromeric epithelium. Henceforth the translocation of the groove is, as stated on p. 13, only apparent. In other words, the obliteration of the segmentation cavity by the invagination of the macromeric hemisphere, is very little when compared with the reduction of it by the shifting backwards of the micromeric epithelium. In this way the segmentation cavity is at length entirely obliterated long before accomplishment of the gastrulation (*Fig. 21*); and consequently the boundary groove is also lost from sight.

The invagination of the macromeric hemisphere and the backward shifting of the outer micromeric layer represent, however, by no means the sole cause for the obliteration of segmentation cavity. The macromeres which form a part of the hemisphere

in the neighbourhood of the cavity lose their mutual union, thus disturbing the sharp contour of the cavity; and furthermore, some scattered cells come to fill up the last remnant of the cavity, which is thus entirely obliterated (*Figs. 21 and 30*).

The loosening of the cellular union of the macromeres, which is doubtless a very remarkable occurrence, is not confined to the neighbourhood of the segmentation cavity where it first takes place, but eventually extends over a wider extent and especially to the ventral part. Even the whole mass of the cells may be more or less influenced by the process (*Fig. 21 and 22*). The main mass of the hemisphere formed of macromeric elements has hitherto been in firm union, so as to give them a polyhedral shape by mutual pressure and to cause the sharp contour against the segmentation cavity. This close union has been, I believe, kept up owing to the pressure exerted by the liquid contents of the segmentation cavity upon the cell-mass. The pressure is probably intensified by stages with growing reduction of the cavity. Upon this pressure, as before stated, depends also the external form of the boundary groove during invagination, it having the effect of distending the animal layer. The liquid is at length forced to escape in some way as the cavity is by stages reduced; it is probably pressed out through the outer micromeric layer when the pressure attains the maximum. As soon as this happens, the pressure is suddenly much weakened, and the loosening of the cellular union should set in. The segmentation cavity is thus obliterated.

In the gastrula thus brought forth, the invaginated parts of the ovum, including the micromeric and macromeric parts, will be called the entoderm, while the micromeric epithelium which

remains as the external coat of the ovum merits the name of the ectoderm.

Having described above the main course of the gastrulation, I may be permitted to give some more considerations on a few points :

1. I have stated before that I have come to consider the stage given in *Fig. 1* as an old morula stage, and not as a blastula. This is due to the following consideration. It seems to me correct that under the term "blastula" is understood a stage in which blastomeres are no longer in a merely aggregated state, but are converted into the form of an epithelium, since this histologically differentiated condition ought certainly to be distinguished from the stages that consist of indifferent cells only, as is very obvious in *Amphioxus*. Applying this view to the present case, the stage given in *Fig. 1* is not really gone further than an old morula. In this case the blastulation, as indicated by differentiation of the blastomeres into an epithelium, should be looked upon as being much delayed ; it is still being carried on during the whole period of the gastrulation and is finished only a little earlier than the latter process. In other words, the two processes, blastulation and gastrulation, overlap each other to a great extent in the period of their occurrence. The prime cause of this belated mode of development is indisputably due to delay of segmentation on account of an enormous accumulation of yolk within the ovum.

2. I have not been able to detect in any stage what might be considered as "concrecence." It is true that at a much later stage when the embryo begins to grow in its long axis,

there is detected, in a small extent of the hind region, a process which resembles concrescence. But that seems to me to be of a significance different from the process which embryologists are wont to call by the name just mentioned; the process observed by me is probably identical with that which was pointed out in the Amphibia by Eycleshymer.¹⁾

3. I have stated that the macromeric hemisphere has an activity of its own. This is an important factor in bringing about the gastrulation in *Petromyzon*. That such is the case in the *Petromyzon* ovum which contains much larger quantity of yolk than the frog's ovum and that there is no yolk-plug in the former are very striking facts. I can find no other way of explaining this peculiarity than by assuming the frog's ovum to be secondarily holoblastic as was maintained by Professor Mitsukuri seven years ago.²⁾ I intend to deal with this question more fully at another place.

I wish to express my deepest thanks to Professor Mitsukuri for his kindness in looking through the manuscript.

Nov. 26, 1905.

1) A. C. Eycleshymer: The Formation of the Embryo of *Necturus*, with Remarks on the Theory of Concrescence. *Anat. Anz.*, Bd. XXI, 1902.

2) K. Mitsukuri: On the Fate of the Blastopore, the Relations of the Primitive Streak, and the Formation of the Posterior End of the Embryo in *Chelonia*, together with Remarks on the Nature of Meloblastic Ova in Vertebrates. *Journ. Coll. Sc., Imp. Univ., Tokyo*, vol. X, 1896.

Explanations of Plates.

List of Abbreviations.

<i>a.h.</i>Animal hemisphere.	<i>mic.ep.</i> ...Micromeric epithelium.
<i>ar.en</i>Archenteron.	<i>m.g.</i>Medullary groove.
<i>b.g.</i>Boundary groove.	<i>p.m.</i>Peristomal mesoderm.
<i>bp</i>Blastopore.	<i>s.c.</i>Segmentation cavity.
<i>bp.l.</i>Blastoporic lip.	<i>v.h.</i>Vegetative hemisphere.
<i>c.em</i>Conical eminence.	<i>vl.bp.</i>Ventral lip of blastopore.
<i>ch</i>Chorion.	+Boundary between micro-
<i>em.s.</i>Embryonic shield.	meric and macromeric
<i>g.m.</i>Gastral mesoderm.	epithelia in archenteric
<i>i. mic. ep.</i> ...Inner micromeric epithel-	roof.
ium.	*Anterior blind end of
<i>l. mac. ep.</i> ...Lateral irregular epithel-	archenteron.
ium.	**Disturbed part of macro-
<i>macm</i>Macromeres (macromeric	meric cell-mass.
layer).	‡Lower limit of micromeres.
<i>mac. ep.</i> ...Macromeric epithelium.	‡*Flattened part of vege-
<i>micm</i>Micromeres (micromeric	tative hemisphere.
layer).	

Plate I.

Surface views of the ova undergoing the process of gastrulation. The figures were all drawn by the author from living specimens. The magnification is about $\times 30$ for all the figures.

Fig. 1—An old morula. The upper translucent part (*a.h.*) is the animal hemisphere; the lower opaque part (*v.h.*) is the vegetative hemisphere.

Fig. 2—A fully grown morula. The animal hemisphere (*a.h.*) has become much larger than that in the stage of *Fig. 1*, while the vegetative hemisphere (*v.h.*) is rather reduced in extent.

Fig. 3a—Side view of a little further advanced ovum. The conical eminence (*c.em.*) appears as a rounded elevation. The boundary groove (*b.g.*) has come into view.

Fig. 3b—Dorsal view of the same ovum. The proportion of the extent of the animal and vegetative hemispheres is well seen; the latter is about $\frac{1}{4}$ of the former in bulk.

Fig. 4a—Side view of a little further developed ovum. The conical eminence (*c.em.*) has become prominent, and a part of the vegetative hemisphere below the eminence has flattened ($\frac{\pi}{2}$). The boundary groove (*b.g.*) has become deeper and is extended farther ventrally.

Fig. 4b—Dorsal view of the same ovum. A comparison of this with *Fig. 3b* shows that the part giving rise to the conical eminence is strongly compressed from side to side.

Fig. 5a—Side view of an ovum in which the gastrula invagination has just begun (*bp.*); the boundary groove (*b.g.*) has extended itself farther ventrally.

Fig. 5b—Dorsal view of the same ovum. The blastopore (*bp.*) is seen like a nail-mark below the conical eminence (*c.em.*).

Fig. 6a—Side view of an ovum in which the invagination has gone a little further.

Fig. 6b—Dorsal view of the same ovum. The conical eminence is converted into a flattened and broad elevation (*em.s.*), the embryonic shield, and consequently the boundary groove (*b.g.*) is curved anteriorly.

Fig. 6c—The same ovum from the basal surface. The crescentic blastopore (*bp.*) has increased in length of both its limbs.

Fig. 7a—Side view of a further advanced ovum. The constriction of the boundary groove (*b.g.*) is not only striking, but now surrounds the ovum completely. While the invagination is further carried on, the basal surface is depressed and flattened further ventrally.

Fig. 7b—Dorsal view of the same ovum. The embryonic shield (*em.s.*) has become broader, and the boundary groove (*b.g.*) has shifted anteriorly in consequence of the advancing invagination.

Fig. 7c—Basal view of the same ovum. The invaginating groove (*bp.*) is much extended, describing an almost semicircular arc. It is bounded outside by the blastoporic lip (*bp.l.*) of the same form and which is most prominent in the middle part. The field contained within the arc is depressed a great deal, and the depression is deeper towards the steepest middle part of the blastoporic lip, thus presenting a wide-gaped blastopore of a funnel-like shape.

Fig. 8a—Side view of an ovum in which the translucent part is reduced, in consequence of the progressing invagination, into a small vesicle at the anterior end of the ovum and is separated from the opaque embryonic shield by the strongly curved boundary groove (*b.g.*).

Fig. 8b—Dorsal view of the same ovum. The larger part of the ovum is occupied by the opaque solid part, the embryonic shield (*em. s.*); capping this is seen the small translucent vesicle at the anterior end.

Fig. 8c—Basal view of the same ovum. Both limbs of the arc described by the blastoporic lip (*bp.l.*) are brought nearer to the median line and to each other, while the blastoporic depression has become deeper than before.

Fig. 9a—Side view of a further advanced ovum. The whole extent of the dorsal surface is occupied by the embryonic shield (*em.s.*). The translucent vesicle is driven into the ventral side of the anterior part and is seen as a slight swelling. A great deal of the vegetative hemisphere remains still exposed; accordingly, the ovum is somewhat conical in shape, the posterior part being bulged out.

Fig. 9b—Dorsal view of the same ovum. The translucent vesicle can not be seen, while the boundary groove is perceived as two slight indentations on both sides of the anterior end (*b.g.*).

Fig. 9c—Basal view of the same ovum. The blastoporic depression (*bp.*) has become deeper and narrower, but ventrally it passes over gradually into the vegetative field which is still spherical in shape, wanting as yet the ventral blastoporic lip.

Fig. 10a—Side view of a further advanced ovum. There is no longer seen any trace of the translucent vesicle. The segmentation cavity is thoroughly obliterated. The ovum now assumes a pear-shape, being larger in the anterior part and lessening in bulk posteriorly.

Fig. 10b—Dorsal view of the same ovum. The dorsal surface is no longer plain as before, but there is expressed an oval elevation (*m.p.*), the medullary plate, along the median line of which is seen the "Rückenrinne" running lengthwise. This is deeper towards the posterior end and communicates with the blastopore, while anteriorly it is shallower and fades away at length.

Fig. 11a—Side view of a much advanced ovum. The medullary plate is converted into a pair of prominent medullary ridges (*m.r.*). The ventral lip of the blastopore (*vl.bp.*) is now established.

Fig. 11b—The same ovum seen from the dorsal and posterior sides. The blastopore shows its definitive circular form by the establishment of the ventral lip (*vl.bp.*)

Plate II.

Fig. 12—A section through both the animal and vegetative poles of an ovum a little younger than that represented in *Fig. 1*. The segmentation of the blastomeres are being actively carried on. The macro- and micro-meres project into the semilunar segmentation cavity, and some of them are even detached and nearly free in that cavity. $\times 64$.

Fig. 13—A section through both the poles of an ovum, the same in development as the surface view shown in *Fig. 2*. The ovum is ellipsoidal in shape; accordingly, the segmentation cavity is no longer semilunar in outline, but is circular. Segmentation is over. The blastomeric wall (*micrm.* and *macrm.*) shows not only a sharp contour against the segmentation cavity, but is reduced in thickness. $\times 64$.

Fig. 14—A median sagittal section through an ovum, nearly the same in development as the stage shown in *Fig. 3a*. The relation of

the conical eminence (*c.em.*) to the boundary groove (*b.g.*) is very well seen. The micromeric part is transformed into a columnar epithelium (*mic.ep.*) at a small area in the groove. $\times 64$.

Fig. 15—A median sagittal section through an ovum, about the same in development as the surface view represented in *Fig. 4a*. The conical eminence (*c.em.*) is distinct; accordingly, the boundary groove (*b.g.*) is deep, and a small field of the macromeric hemisphere immediately below the eminence is flattened ($\frac{**}{**}$). $\times 64$.

Fig. 16—A median sagittal section through an ovum of about the same stage as that shown in *Fig. 5a*. The commencing gastrula invagination (*bp.*) is well seen. The conical eminence and the boundary groove are conspicuous. The floor of the segmentation cavity opposite the invaginating blastopore (*bp.*) is a little raised into that cavity. $\times 64$.

Fig. 17—A median sagittal section through an ovum a little older than the surface view given in *Fig. 6a*. The boundary groove has somewhat shifted anteriorly, being pressed by the invagination of the macromeres which formerly formed the conical eminence and which now take an epithelial arrangement (*mac.ep.*). The archenteron has appeared for the first time. The differentiation of the micromeres into the columnar epithelium (*mic.ep.*) has extended over an increased area. The wrinkled chorion (*ch.*) is to be seen. $\times 64$.

Fig. 18—A median sagittal section through an ovum of about the same stage as the surface view shown in *Fig. 7a*. The archenteron (*ar.en.*) and the macromeric epithelium (*mac.ep.*) roofing the cavity have increased in extent. The boundary groove (*b.g.*) has shifted farther anteriorly, and the segmentation cavity (*s.c.*) is much reduced. Some macromeres outside the anterior blind end of the archenteron are in a disturbed state ($\frac{**}{**}$). $\times 80$.

Fig. 19—A median sagittal section through an ovum as much advanced as the stage represented in *Fig. 8a*. Not only the archenteron (*ar.en.*) and the macromeric roof of it (*mac.ep.*) have increased in extent, but in the posterior section of the roof there have come into view the micromeric epithelium (*i.mic.ep.*), which may be distinguished from the macromeric part lying anteriorly to the point marked with + by the regular arrangement of cells as well as by their smaller nuclei. The boundary groove

(*b.g.*) has shifted far anteriorly, and the segmentation cavity (*s.c.*) is very much reduced. Some disturbed macromeres (**) are seen outside the blind end of the archenteric canal. $\times 80$.

Plate III.

Fig. 20—A median sagittal section through an ovum a little further advanced than that shown in surface view in *Fig. 9a*. The archenteron (*ar.en.*) has further extended, this extension being made by further invagination of the macromeres as well as by new addition of micromeric epithelium. The segmentation cavity (*s.c.*) is reduced into a narrow space; the boundary groove (*b.g.*) is marked by a slight depression on the ventral surface of the last remnant of the segmentation cavity, which is about to be obliterated by the falling in of the macromeres loosened from mutual union. $\times 80$.

Fig. 21—A median sagittal section through an ovum of about the same development as the surface view given in *Fig. 10a*. The archenteron (*ar.en.*) is much increased in extent; its anterior part strikes against the peristomal part of the mesoderm (*p.m.*) now formed, thus entirely obliterating the segmentation cavity. The micromeric section of the archenteric roof has greatly enlarged so that nearly two-thirds of the latter is taken up by the micromeric epithelium (*i.mic.ep.*); a small part of the macromeric field still remains uninvaginated. The strongly wrinkled chorion (*ch.*) is shown. $\times 80$.

Fig. 22—A median sagittal section of a much advanced ovum which is, however, a little younger than the ovum figured in *Fig. 11a*. The process of gastrulation is finished. There is no trace of the macromeric field outside. The outer (*e.mic.ep.*) as well as the inner (*i.mic.ep.*) micromeric epithelia show a compact texture. The anterior part of the archenteron is lost from sight; the cells which formerly formed the wall at this part are now indistinguishable from other macromeric elements which have lost their mutual union. The peristomal mesoderm (*p.m.*) is well established. $\times 80$.

Fig. 23—A piece of a sagittal section through an ovum a little younger than that represented in *Fig. 14*. The left side is the outer surface, and the right represents the surface turned towards the

segmentation cavity. I have endeavoured to show here the transitional part of the micromeric to the macromeric layer and the mode in which the micromeric layer of many cells in thickness (*micm.*) passes over into the columnar epithelium (*mic. ep.*). Besides the difference in size of cells the nuclei contained in the micromeres (upper part of the figure) are much smaller than those in the macromeres (lower part); this contrast is, in this section, especially sharply expressed. The lighter colour of the micromeric part is due to the smaller quantity of yolk-granules contained. The epithelially differentiated part passes over, on one hand, abruptly into the macromeric part formed of a crowd of larger cells and, on the other hand, into the micromeric layer which is not yet well established but is formed of cells wedged in between one another in a dovetail-like manner. $\times 180$.

Fig. 24—A transverse section through the dorsal part of an ovum about as far developed as that shown in *Fig. 10a*. The distinctive characteristics of the two kinds of cells are the same as given in the explanation of *Fig. 23*. Between the outer (*e.mic.ep.*) and the inner (*i.mic.ep.*) micromeric epithelium no difference in histological nature can be detected. The cells of the inner epithelium forming the roof of the archenteron proliferate on either side of the layer and give rise to cells of the same kind (*gm.*), and which are destined to establish the gastral part of the mesoderm. The concave surface of the archenteric floor is nothing else than the depression or funnel-groove of the exposed macromeric field. $\times 180$.

Fig. 25—A frontal section through the blastopore of an ovum of about the same stage as that represented in *Fig. 7a*. A large notch (*bp.*) at the lower end shows the blastoporic depression on the macromeric field. The macromeric surface is almost entirely withdrawn, and the lateral lips on either side of the notch are covered with the micromeric epithelium. A shallow depression on either side (*bg.*) represents the boundary groove. As the section passes through the dorsal part, the segmentation cavity (*s.c.*) is comparatively small; on the contrary, the disturbed part of the macromeres (***) is met with in its whole breadth. The micromeric layer (*mic.ep.*) presents the structure of a columnar epithelium throughout its whole extent. $\times 80$.

Fig. 26—A section from the ventral part of the same series as that shown in *Fig. 25*. The micromeric layer is nowhere differentiated at

all. On the left side, a mere trace of the boundary groove (*b.g.*) is seen. As the plane of the section is inclined toward that side, the groove is not met with on the right side. The macromeric field shows no tendency to invaginate. The disturbed part of the cell-mass is found in this section also. $\times 80$.

Fig. 27—An oblique transverse section through the blastoporic depression of an ovum of a stage intermediate between those represented in *Fig. 8a* and *Fig. 7a*. A shallow depression on the macromeric margin (*bp.*) shows the ventral part of the blastoporic funnel cut through. The archenteron (*ar.en.*) is roofed by the irregular macromeric epithelium (*mac.ep.*). An irregular row of macromeres on either side of and apparently continuous with the roof, (*l.mac.ep.*) represents the lateral irregular epithelium. $\times 80$.

Fig. 28—A more dorsal section from the same series as that just described. The blastopore is represented by a deep notch (*bp.*). Lateral lips formed by the micromeric layer border the notch, this condition being brought about in consequence of complete withdrawal of the macromeres. $\times 80$.

Fig. 29—A still more dorsal section from the same series, passing through the dorsal lip of the blastopore. The micromeric epithelium (*i.mic.ep.*) is reflected to form the archenteric roof, while the depressed macromeric field which has been withdrawn represents the archenteric floor. As the section is an oblique one, the anterior part of the archenteron is cut through lengthwise to some extent (the upper part of the figure). $\times 80$.

Fig. 30—A horizontal section through an ovum a little younger than the stage represented in *Fig. 10a*. In the anterior part (the left part in the figure), the section passes through the dorsal blastoporic lip. The archenteric roof (*i.mic.ep.*) is cut through obliquely, while the posterior part (the right part in the figure) shows in section the ventral part beyond the anterior end of the archenteron. The lateral irregular epithelium (*l. mac. ep.*) is seen as a continuous layer. $\times 80$.





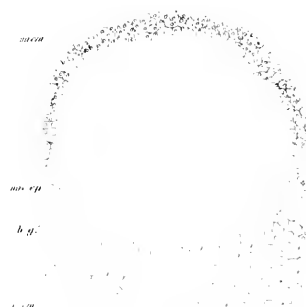
12.



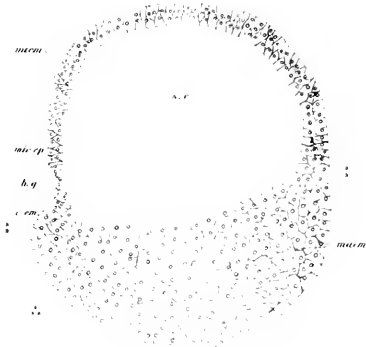
13.



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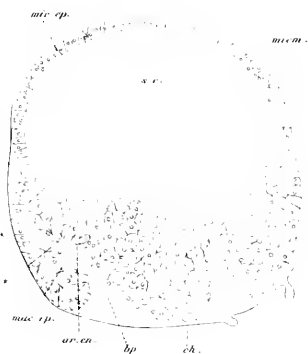
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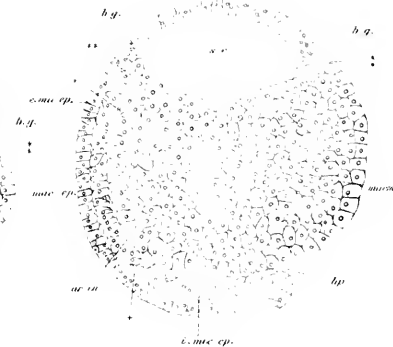
17.

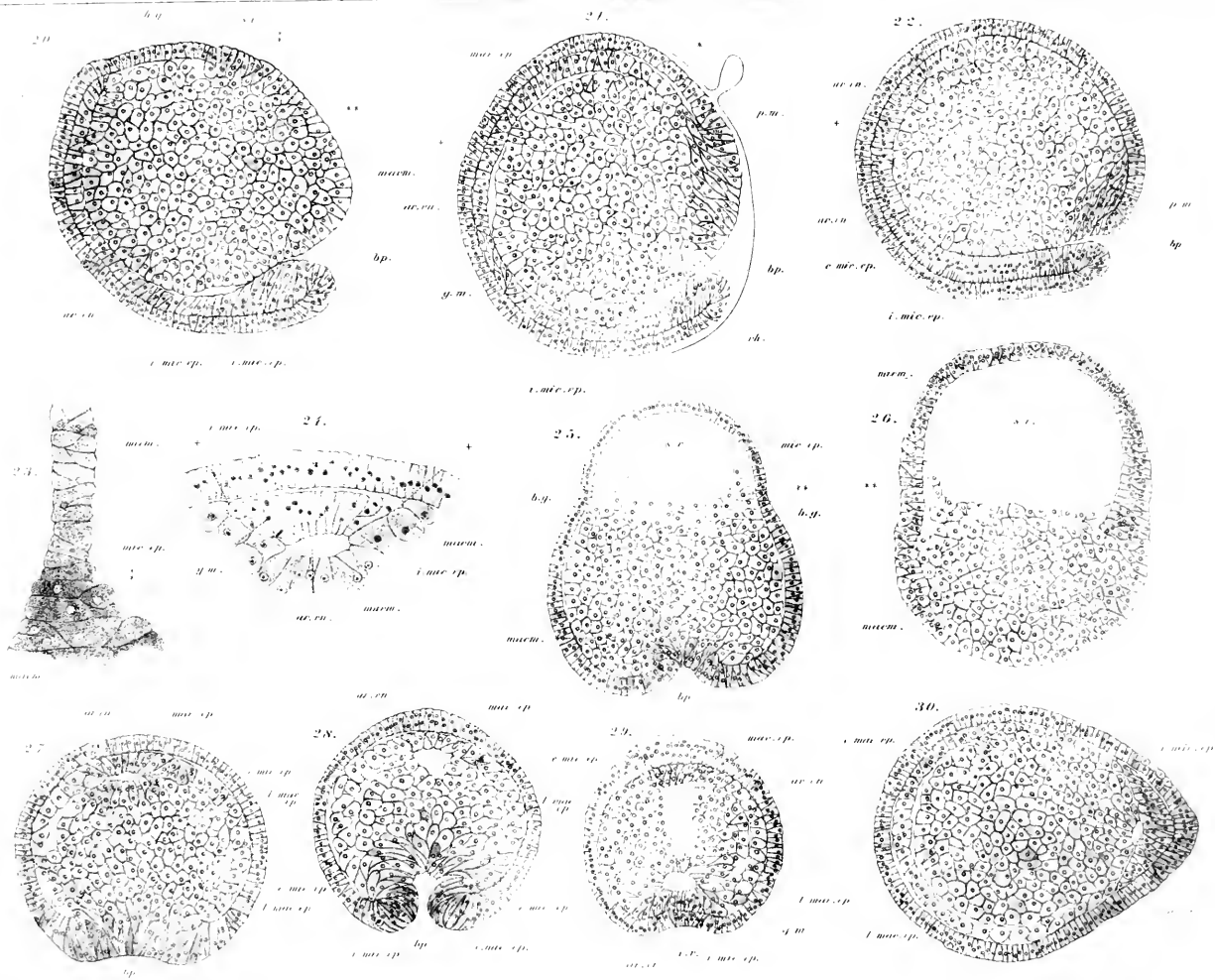


18.



19.





The Fucaceæ of Japan.

By

K. Yendo, *Rigakushi*.

With 18 plates.

INTRODUCTION.

The family *Fucaceæ* (*Cyclosporeæ*) is in the present paper taken with the same limitations as by KJELLMAN¹⁾ in ENGLER and PRANTL's "Die Natürlichen Pflanzenfamilien," in which he included the *Sargassaceæ* and *Fucaceæ* of other systematists.

In the "Nippon Sōrui Mēi" (Enumeration of the Algæ of Japan) published by Dr. K. OKAMURA²⁾ in 1902, 56 species of Fucaceous algæ are mentioned under 7 genera. The list comprises all known species from Japan reported by various botanists up to that date. Among those mentioned, 39 species belong to the genus *Sargassum*, 8 to *Cystophyllum*, and one or two to each of the remaining genera.

The first knowledge of Japanese *Sargassum* we owe to the elaborate work of TURNER.³⁾ A few species more were added by various European algologists, such as C. AGARDH,⁴⁾ KÜTZING⁵⁾

1) 1 Theil. 2. Abth. p. 268.

2) pp. 137-160.

3) Historia Fucorum. 1808-1818.

4) Species Algarum. 1821, 1828.

5) Ueber die Eigenthümlichkeit der Vegetation in die chinesischen und japanischen Meeren—Botanische Zeitung, 1843. s. 53-57.

and HARVEY.¹⁾ In his classical work "Species Sargassorum Australiæ," J. AGARDH revised all the species of *Sargassum* known from the Australian seas as well as those from the coast of Japan and the Indian Ocean, adding at the same time, a large number of new species described by him. He²⁾ again revised *Sargassum* of Japan in "Analecta Algologica" and added a few other species. Before the last mentioned publication appeared DE TONI included all known species up to that time in his "Sylloge Algarum." The Japanese forms mentioned in that work numbered 39 species and 3 varieties inclusive of the doubtful species described by the early writers. OKAMURA's enumeration noted above is based entirely upon DE TONI's work.

Any one who tries to touch upon the *Sargassum* and *Cystophyl-lum* of Japan encounters the utmost difficulty in identifying the specimens with the descriptions. The plants under these genera vary greatly in their morphological characters according to the age of the individual and the conditions of its environment: and not a few species have their upper parts so wholly unlike their lower portions, that it would be quite impossible to imagine the former in cases in which the latter alone were given. Many of the species assigned to the coast of Japan and established by European botanists were based upon fragmentary and sterile specimens of such variable plants as mentioned above found floating on the sea or cast ashore. And moreover the species described by HARVEY and by J. AGARDH have never been illustrated. The present writer could not restrain an exclamation of impatience at a diagnosis of a few lines which was satisfactorily

1) Characters of New Algae chiefly from Japan and adjacent Regions collected by CHARLES WRIGHT in the North Pacific Expedition under Captain RODGERS.—Proceedings of the American Academy of Art and Science. Vol. V. 1859, p. 327-334.

2) De Speciebus Sargassorum Japonicis Scholia. (Anal. Algol. cont. III. p. 49-61).

applicable to several entirely different species. It must be confessed that the most puzzling points in the course of the present study lay in such descriptions and their derivations. As will be found in this paper, among the 39 species of *Sargassum* hitherto annexed to the Japanese algal flora only 18 seem to me to remain as "good" species. The accompanying plates, superfluous as some of them may seem, will give no small advantage to those who may hereafter touch upon the *Fucaceæ* of Japan.

The morphological characters of *Sargassum* have been minutely discussed by J. AGARDH in "Species Sargassorum Australiae," and few points need further remark. His observations, however, seem to me, undoubtedly to have been based upon herbarium specimens. Close observation of the plants *in vivo* may reveal interesting and important facts to amplify or to modify his conclusions. Some points which are directly connected with Japanese forms will be noted in the present paper under the species concerned.

Among the members which are grouped in the series *Acanthocarpicæ* J. Ag. and *Malacocarpicæ* J. Ag. under the subgenus *Eusargassum* J. Ag., there are not a few species which cannot be separated from one another without a knowledge of the reproductive organs. GRUNOW¹⁾ seems to have believed that *Sargassum polycystum* is a diœcious plant with smooth male receptacles and prickly female ones. If the presence or absence of the prickly processes on the receptacle be due to the sex, then there is no reason for separating the *Acanthocarpicæ* from the *Malacocarpicæ*. This question, however, is not yet satisfactorily settled. The plant which I have identified as *Sargassum*

1) Forschungsreise der Gazelle, p. 26.

Illicifolium var. *duplicatum* in the present paper had some of its receptacles quite smooth and some undoubtedly prickly; and a male plant referable, though not without some hesitation, to the same species is provided with prickly receptacles. These facts seem to disprove GRUNOW's remark.

O'KUNTZE revised the *Sargassum* species in 1881¹⁾ and in 1898.²⁾ In so far as it relates to the Japanese species his view is so divergent from that of the systematists of the present day that I can not venture to follow his specific arrangement. He seems to have taken the relative positions of receptacles, vesicles, and leaves in an individual as characters of little importance in defining a species. As a result, some of the members of *Cystophyllum* in our classification are by him referred to *Sargassum*. I have therefore found it advisable not to take his opinions into consideration in the present work except on one or two points.

The present study was first suggested by Dr. K. KISHINOUE of the Imperial Fisheries Bureau of the Department of Agriculture and Commerce. In 1902, circulars were sent to twenty two Marine Experiment Stations along our coasts, requesting the collection of specimens of *Sargassum* and its allies. Numerous specimens of the genus mentioned as well as of *Cystophyllum*, etc., all entire and perfect, were sent to the Bureau. The material was examined carefully together with the dried specimens in the writer's herbarium. For certain reasons the study could not be carried on under the Bureau and all of the material was entrusted to the writer for the execution of the work.

1) Revision von *Sargassum* u. das sogenannte Sargasso Meer. ENGLER'S Bot. Jahrb. Bd. 1. 1881.

2) Revisio Genera Plantarum. III. II.

In the year 1905, the results were published as a preliminary report on the Fucaceous algae of Japan in the Tokyo Botanical Magazine.¹⁾ In that report the present writer asked for the loan of specimens to enable him to secure as complete data as possible in discussing the distribution of the family on our coasts, and several botanists who had specimens in their herbaria kindly forwarded them for the writer's examination. Prof. K. MIYABE who had for twenty years carefully studied the marine flora of Hokkaido placed all his collection, together with that of the Fisheries Department of the Hokkaido Local Government, at the writer's disposal. These extensive collections have thrown much light upon the northern species, as may be seen under the proper headings. The present writer may declare with assurance that few species of the family *Fucaceæ*, if any, are likely to be found in Hokkaido to be added to the present work. Only by the unequalled kindness of Prof. MIYABE was such a result possible. A species found in his collection, undoubtedly new to science, is described in this paper under the name *Sargassum Miyabei* in recognition of his generosity.

Greatly to the regret of the writer it is necessary to say that the coast of Loochoo as well as that of the southern parts of the Kiushiu Islands have not been thoroughly botanized. The specimens from those localities were few in number and often fragmentary. Many of them belonged to the "duplicate-leaved" form, the most questionable members of *Sargassum*. Some of them were sent to Major THEO. REINOLD for his opinion on them; and he was so kind as to take the trouble to compare them with the authentic specimens and to give invaluable advice

1) Vol. 19, No. 222, pp. 149-161.

to the writer. The whole responsibility, however, with respect to the references and determination, rests with the present author.

The species described by HARVEY as new, in his paper entitled "Characters of New Algæ," l. c., were not described in full, and none of them were illustrated by the author or by any subsequent botanist. These species, indeed, have been the hardest nuts to crack in the study of the *Sargassum* of Japan. Prof. P. E. WRIGHT of Trinity College, Dublin, where the original specimens of HARVEY's species are kept, generously saved me much time and trouble, by picking out the specimens and taking photographs of each. If HARVEY's species are in the present paper correctly determined, which the writer may hope to be the case, it is due to the generous help of Professor WRIGHT.

The best thanks of the writer are due to Prof. Dr. J. MATSUMURA under whose care the present work has been carried on; and the writer can not sufficiently express his thankfulness to Dr. K. KISHINOUE, Prof. K. MIYABE, Major THEO. REINBOLD and Prof. P. WRIGHT for their kind help in the ways noted above. To Prof. Dr. M. MIYOSHI, Dr. K. OKAMURA and others he begs to acknowledge his indebtedness for help given him in references or specimens which were indispensable in the course of this study.

TOKYO, NOVEMBER, 1906.

DISTRIBUTION OF FUCACEOUS ALGÆ ON THE COAST OF JAPAN.

The distribution of marine algæ along the coast of Japan was first discussed by Dr. OKAMURA¹⁾ in 1892. The data at that time were by no means ample enough to make the results conclusive; for our knowledge of the marine flora of the Kuriles and of Loochoo was very scanty. Yet the paper is of great value even at present and no fundamental alteration is to be expected in the results. In the year 1901, at the "Minnesota Seaside Station" I gave a brief sketch of the distribution of the marine flora of Japan. It was published in "Postelsia," No. I.,²⁾ the year-book of that station for 1901. In it the whole algal regions of Japan was briefly divided as follows:—

(a) Pacific side.

1. From the Kurile Islands to Kinkwasan Island.
2. From Kinkwasan Island to the southern end of the Kiushiu Islands.
3. From the southern end of the Kiushiu Islands to Formosa.

(b) Japan Sea side.

1. From Iki Island to Ojika peninsula.
2. From Ojika Peninsula to the north.

That the distribution of marine algæ is greatly influenced by prevailing ocean currents is beyond all doubt. To discuss the algal regions of Japan, therefore, it is not unnecessary to explain the prevailing ocean currents along the coast of Japan. This was once done in "Postelsia," l. c. But as the latter publication

1) The Tokyo Botanical Magazine, Vol. VI. No. 60, pp. 56-60, 1892.

2) pp. 179-192. cf. also Bot. Centralbl. Bd. XCI, p. 41, 1903.

has only a limited circulation it will be preferable to repeat the explanation here.

The two prevailing ocean currents along the coast of Japan may be briefly described as a warm and a cold current. The warm current is the main north equatorial stream, which, turning towards the north in the Philippines, runs along the Loochoo Islands. At the Kiushin Islands, it divides into two streams, the main or eastern being known as the Japan or Black Current. This runs still farther northward and northeastward to Vancouver Island, on the opposite side of the Pacific Ocean. It is this current which washes the east coast of the Main Island (Honshū) of the Japanese Archipelago, running as far north as Kinkwasan Island in the summer, but in winter it is pushed aside by the cold stream from the Behring Sea, so that at that time of the year it cannot be traced farther north than Cape Inuboi.

The lesser of the two branches of the north equatorial stream is known as the Korean or Tsushima Current. It washes the western coast of the Kiushiu Islands and flows into the Japan Sea through Tsushima Strait. Although this branch is a rather weak stream as compared with the eastern current, it travels farther north, washing the west coast of Japan, and passes out through Soya Strait toward the east. Its final end may be traced though faintly on the Ochotsk side of the south Kurile or Etorofu Island.

The main cold currents are likewise two in number. One of them originates at Behring Strait and runs south-westward along the coast of the Kurile Islands and washes the south-eastern coast of Hokkaido (Yezo). Bending southward it disappears in the Pacific near Kinkwasan Island in summer, and at Cape Inuboi in winter. These two points off the coast of

Japan, where the currents meet, are dreaded by mariners on account of the rough water.

The other cold current comes down along the west coast of Saghalin Island, washing the east coasts of Siberia and Korea. Of this current only a small portion touches the west coast of Hokkaido as an undercurrent. Thus the Japan Sea, with the subtropical current on the Japanese side, and the arctic on the Siberian side, shows remarkable climatic differences at places having the same latitude. Otaru, where ice is unknown in the harbour, lies on the same parallel with Vladivostock, ice-blockaded for nearly half the year.

Hakodate, situated on the Tsugaru strait between the Main Island (Honshū) and Hokkaido, has an especially interesting flora. A branch of the eastern cold current escapes to the Japan Sea, washing the Hokkaido side of the strait, and the western warm current enters the same strait along the Honshū shore.¹⁾

The following table is to illustrate the specific distribution of Fucaceæ along the whole coast of Japan. The localities are arranged in order beginning at the southern part of the Japan Sea side and going northwards, including almost all provinces on that side as far as Saghalin, thence turning to the Ochotsk coast of Hokkaido and the Kuriles. In the next, the Pacific coast of the Kuriles comes first and the rocky shores of Hokkaido, the Main Island, Shikoku, and Kinshin are traced province after province southwards. Two provinces, Oshima in Hokkaido, and Mutsu in the Main Island are mentioned twice, these provinces being separated by the Tsugaru strait through which the two great ocean currents

1) For precise accounts of the currents of the Tsugaru strait, see:—YENDO; Cause of the decrease of seaweeds in the Prefecture of Aomori (Journ. of the Imp. Fisch. Bureau) Vol. XII. No. 2. pp. 66-67.

communicate. The coasts of some of the provinces consist in the greater part of sandy beaches, and consequently only a few species have been reported from them; such species are either not considered in the table, or they are attributed to the neighbouring provinces. This will not cause any deception in discussing the distributive features at large.

I should here confess that the material in our hands by no means covers all the existing species on our coast. The southern seas, especially, may supply us with no small number of species as yet unknown, as has been hinted above. However, the data I have been able to procure up to date are ample enough to give sufficient knowledge of the distribution of the family along the coast of Japan. A few remarks on the facts shown in the table will not be superfluous if added here.

1. The species which belong to the genus *Fucus* are strictly limited to the coasts of Hokkaido and the Kurile islands. *Pelvetia* has similar limitations. But the latter does not occur in the northern Kuriles, and one of its formæ extends, though in a less luxuriant state, as far south as Kinkwasan Island. These two genera may stand as representatives of the region extending from the Kurile Islands to Kinkwasan Island. Besides, *Cystophyllum geminatum*, *C. crassipes*, *C. hakodatense*, *Sargassum Kjellmanianum* and *S. Thunbergii* f. *latifolia* are confined to the same region.

2. *Sargassum* is quantitatively as well as qualitatively poor along the northern coast of Hokkaido. It is especially interesting to note that on the northeast coast of Hokkaido we find only two cold-sea forms of *Sargassum*, *S. Kjellmanianum* and *S. Thunbergii* f. *latifolia*. *Sargassum Horneri*, *S. Ringgoldianum*, *S. enerre*, *Cystophyllum sisymbrioides*, etc., are the most common

forms of the Pacific and of the Japan Sea side of middle Japan. Late in the spring these species are found in such luxuriance that fishermen experience considerable trouble in running their boats over the dense vegetation. On the northeast coast of Hokkaido none of these species occur even scantily, but instead of them *Cystophyllum crassipes* and *C. geminatum* are found in similar luxuriance. In June, the port of Nemuro is so filled up with *C. crassipes* that a steam launch can hardly navigate the port without the blades of its propeller becoming entangled in the fronds of the weed.

3. The strait of Tsugaru is an outlet of the Tsushima current from the Japan Sea to the Pacific Ocean. This is satisfactorily illustrated in the table. *Coccophora Langsdorffii* has been reported from the provinces of Echigo, Sado, and Noto, all on the coast of the Japan Sea. The present writer found the same species along both sides of the above mentioned strait and could trace it to the Pacific coast of the Province of Mutsu. Again *Sargassum confusum* is found in the Japan Sea in considerable quantities. On the Pacific coast, however, it is confined to the provinces of Mutsu and Rikuchū; both provinces are on or near the outlet of the strait on the Pacific side.

4. The coasts of the Inland Sea which is surrounded by Shikoku, Kiushiu and the western part of the Main Island, were known to us to be poor in algae. A few species of *Sargassum* and *Cystophyllum*, with badly developed fronds, were the only specimens I could get from that sea.

5. *Cystoseira* is confined to the Loochoo archipelago; and *Cystoseira Sonderi* was reported by DICKIE from the southern end of the Province of Kii. The occurrence of this same species there is to be doubted, as nobody else has collected the

species anywhere within our boundaries. There is no reason, however, to deny the occurrence of a *Cystoseira* species on the coast of that province. I actually collected *Marchesettia spongioides* and *Vanvoorstia spectabilis*, which occur in Loochoo and are undoubtedly tropical, some years ago in the southern part of the Province of Kii but at no place further north. There will be no great error in taking *Cystoseira* as a representative, in Japan, of the algæ of the subtropical waters; in other words, of the region from the southern end of the Kiushiu Islands to Formosa. The species of *Sargassum* under the series *Acanthocarpiceæ* J. Ag. flourish mainly within this region.

6. The Pacific and the Japan Sea side have many species in common. Both sides, however, differ more or less in having several species peculiar to one or the other of them. Thus:—

Peculiar to the Pacific side.	Peculiar to the Japan Sea side.
<i>Sargassum setaceum</i> .	<i>Sargassum fulvellum</i> .
<i>S. pinnatifidum</i> .	<i>S. confusum</i> .
<i>S. tosaense</i> .	<i>S. confusum</i> f. <i>validum</i> .
<i>S. kashiwajimanum</i> .	<i>S. Thunbergii</i> f. <i>nipponica</i> .
<i>S. kushimotoense</i> .	<i>S. Miyabei</i> .
<i>S. Illicifolium</i> var. <i>duplicatum</i> .	<i>Cystophyllum caespitosum</i> .
<i>S. cristatifolium</i> .	<i>Coccophora Langsdorffii</i> .
<i>S. graminifolium</i> .	<i>C. Imperata</i> .
<i>S. sagamiannum</i> .	
<i>S. nipponicum</i> .	

On both sides the difference of the distributive features is most remarkable in middle Japan, becoming gradually indistinct in the southern seas as well as in Hokkaido.

7. The Ochotsk side of Hokkaido exhibits no peculiarity in specific distribution, but shows to a certain extent the characteristic features of both the Pacific and the Japan Sea sides. It should be remembered that *Sargassum confusum*, which is undoubtedly found in the Tsushima current, also exists on the Ochotsk side of Hokkaido as far north as the southern Kuriles.

8. On the Pacific side, many of the warm-sea forms cease to grow in the region north of the Province of Rikuzen; and the cold-sea forms seldom extend southward beyond the same province. Hence Kinkwasan Island, that lies off the coast of that province, may be taken as the limit of the two. This satisfactorily answers to what has been proved by JORDAN¹⁾ from the ichtheological point of view.

On the Japan Sea side, the Province of Ugo is the northern limit of the warm-sea forms, while the Province of Oshima seems to be the southern limit of the cold-sea forms. It is not certain whether the western shore of the Province of Mutsu is occupied by the northern or by the southern species, as that region has not yet been investigated by botanists. The Ojika peninsula in the Province of Ugo may be at all events not very far from the boundary of the northern and the southern flora of the Japan Sea.

1) JORDAN: the Fish fauna of Japan. (Science, Vol. XIV., No. 354, pp. 545-567, Oct. 1901).

SPECIES.

FUCUS (Tourn.) L.

Fucus evanescens AG.

Plate I. Fig. 1-2.

AG.: Icon. Alg. ined. t. 132.—*Id.*: Spec. 1. p. 92.—J. AG.: Spec. 1. p. 210.—*Id.*: Spetzbr. Alg. II. p. 40.—FARLOW: Alg. of New Engl. p. 101.—KJELLMAN: Om Beringhafv. Alg. p. 34.—*Id.*: Alg. Arct. Sea. p. 202.—KÜTZ.: Tab. Phyc. X. Taf. 42. I. (*non bona*).—DE TONI: Syll. Alg. III. p. 201.—OKAM.: Enumer. Alg. of Jap. p. 137.—SETCH. and GARD.: Alg. N. W. Amer. p. 281.

= *Fucus vesiculosus* var. *evanescens* Kütz.: Spec. p. 589.

= *Fucus vesiculosus* POST. et RUPR.: Ill. Alg. t. 30.

The present species abounds in the northern parts of the Pacific as well as of the Atlantic Ocean. More than a dozen formæ have been described by KJELLMAN from both localities, and SETCHELL and GARDNER¹⁾ added two more from the north-west coast of North America. KJELLMAN²⁾ himself, however, observes that the formæ he described "are certainly connected by numerous intermediate forms, but they deserve however to be mentioned specially, because they show the limits and directions of the species and differ somewhat with regard to biology and geographical distribution." I am strongly of the belief that some of his formæ are nothing but extreme cases of one and the same species, due to age and place of growth. The breadth and texture of the segments of the fronds, and especially the caulescence or non-caulescence of the plants, are characters that are never reliable. Generally speaking, young and sterile individuals have the segments mostly winged down to the basal ones, while

1) SETCHELL and GARDNER: Algæ of N. W. America p. 283.

2) KJELLMAN: Algæ of the Arctic Sea. p. 203.

the old ones almost always have the basal segments reduced to the ribs, and thus the fronds become caulescent. Any one who has ever tried to make a collection of this species, must have recognized that the young branches which have newly started adventitiously from a part of a caulescent segment are short but broadly winged. The size and the shape of the receptacles, too, undoubtedly tend to vary in some degree according to the locality of the plant.

Along the coast of almost the whole of Hokkaido, the present species may be found in greater or less quantities. The vast horizontal reef in the litoral regions of Kataoka Bay, Shimushu Island, is one of the best localities for this species within our boundaries. When we hunt for different forms in such a place we can easily pick up a good number of modifications in the external appearance of the fronds according to the season and the salinity of the water in which they grow. Some of the formæ will be mentioned below. But, as KJELLMAN has already said, quite a number are applicable partly to one forma and partly to another, and often show an intermediate character. The formæ I mention below are by no means all we can find within our boundaries and hence can not be used in the discussion of the geographical distribution or of the limit of the modification of the species. What I can mention here is the occurrence of *Fucus evanescens* in our northern seas, and the extreme variability of its external forms according to the habitat and the season.

More than half of the specimens in our hands, collected from the various parts of Hokkaido, are referable to *f. pergrandis* KJELLM. or to *f. macrocephala* KJELLM. rather than to any other forma. Some of them, however, have the segments much narrower than any reported of the species and a few are

thin and membranaceous in substance. One of the specimens from Shiranuka, Prov. of Kushiro, has the rib quite obsolete above the middle portions of the frond. The specimens from Shari and Shitsunai have some likeness to both *f. contracta* and *f. angusta*, but more closely resemble the latter. They are characterized by well-defined receptacles and minute but prominent, densely aggregated conceptacles (Pl. I. fig. 1.). One of the specimens from Kushiro stands very near to them but has much larger receptacles which measure 1.5–2.5 cm. in length and 1.–1.2 cm. in breadth, bifurcating with wide angles, thus approaching more closely to *f. macrocephala* KJELLM. The specimen from Osatsube is applicable to *f. cornuta* KJELLM., though fragmentary and sterile; but ours has the receptacles simple or only once forked, and most of them are very well defined at the base. KJELLMAN¹⁾ mentions *f. nana* and *f. bursigera* from Spitzbergen Island at the high water mark or in the river mouth. A specimen which approaches these formæ was found at Esashi in the Province of Kitami and is now in the herbarium of the Department of Fisheries of the Hokkaido Local Government; Pl. I. fig. 2 represents a part of it.

Beside the above mentioned formæ others might be pointed out. It would, however, be unimportant to add to algological literature more formal names, established on what I regard as invalid local forms.

Localities: Zenigamezawa (H. H. F.), Shirikishinai (H. H. F.), Todohokke (H. S. A.), Osatsube (H. H. F.), Oshima Prov.; Mororan (H. S. A.) (!), Urakawa (H. H. F.), Shamani (H. S. A.), Saruru (H. S. A.), Iburi Prov.; Shitsunai (H. S. A.), Shoya (H. S. A.), Hidaka Prov.; Shiranuka (H. H. F.), Kushiro(!) (H. S. A.), Kushiro Prov.; Nemuro (!)

1) KJELLMAN: Om Spetzbergens Marina Klor. Thallogh. II. p. 4.

(H. H. F.) (H. S. A.) (OKAMURA); Wennai (H. H. F.), Kunashiri Isl.; Bettobu (H. H. F.), Hitokappu Bay (!), Rubetsu (!), Etorofu Isl.; Shiretoko (H. H. F.), Shari (H. H. F.), Moyoro (H. H. F.), Mombetsu (H. S. A.), Rishiri Isl. (!), Kitami Prov.; Uruppu Isl. (H. H. F.) (H. S. A.) (OKAMURA); Rashowa Isl. (!); Onnekotan Isl. (!); Shashikotan Isl. (!); Poromushiri Isl. (!) (H. S. A.); Shimushu Isl. (!); Yavina, Kamtschatka (!).

Fucus inflatus VAILL. *f. edentatus* ROSENV.

Plate I. Fig. 3.

ROSENV.: Grœnl. p. 834.—BÖRGES.: Mar. Alg. Færøes. p. 465.—SETCHELL and GARD.: Alg. N. W. Amer. p. 280.

= *Fucus edentatus* DE LA PYL.: Flor. d. Terr. Neuv. p. 84.

We have a form of *Fucus* on the east coast of Hokkaido, which resembles *Fucus evanescens* in several respects; but it has narrower laminae and the ribs reach to the ultimate points of the terminal segments. If the vanishing of the ribs at the upper portions of the fronds and the broadness of the laminae have been taken as important points characterizing *Fucus evanescens*, the above must be detached from it, and should be referred to *Fucus inflatus* VAILL.

SETCHELL and GARDNER¹⁾ assign the species, with a few formæ, to the northwest coast of North America. Ours probably is equal to theirs although I could not find a form corresponding to *Fucus inflatus f. filiformis* (*F. filiformis* GMEL.) on our coast.

BÖRGESSEN²⁾ discussed minutely the various forms of *Fucus inflatus* and compared them with the descriptions of former writers. I can not enter upon a criticism of his opinion, as most of the forms belong to the north Atlantic. I am therefore

1) SETCHELL and GARDNER: *Algae of N. W. America*. p. 280-281.

2) BÖRGESSEN: *Marine Algae of Færøes*. p. 466 *et seq.*

obliged to follow implicitly his classification in the determination of the various forms of *Fucus inflatus*.

Our form may be referred to *f. edentatus* ROSENV. with satisfaction, and accords especially well with the figure and description of a plant from Thorshaven, illustrated by BÖRGESSEN in "Marine Alg. of Färöes" fig. 90.

The specimens collected by myself were growing mixed with *Pelvetia Babingtonii f. japonica*. This fact led me to wonder if the plants that I had considered as the high tide form of the latter were not a form of the plant in question. The high tide form of *Pelvetia Babingtonii f. japonica* has indeed some resemblance to *Fucus inflatus f. disticus* as will be stated hereafter. I have no reason to deny the occurrence of the last mentioned forma within our boundaries: the high tide form, however, which I mention below under *Pelvetia Babingtonii f. Wrightii*, may be conclusively proved not to belong to *Fucus inflatus*.

KJELLMAN¹⁾ mentions a single species, *Fucus evanescens*, in his list of Algæ from Bering Strait. He describes several formæ under it from there, but does not give any account of *Fucus inflatus* or forms resembling it.

There are numerous examples in the specimens at our hand which show a character intermediate between *Fucus evanescens* and *Fucus inflatus*: that is, in some segments of a frond the ribs reach to the apices while in others they disappear at some distance from the ultimate points. Among the specimens which I mentioned under the preceding species many have the ribs in some segments quite to the apices.

It may be easily imagined, taking *Fucus inflatus* as a valid species, that in places where the two species occur together,

1) KJELLMAN: Beringhafvets Algflora. p. 34.

hybrids between them may exist in nature. On one side, however, it is not unreasonable to believe that too much stress has been put on the broad laminae and the vanishing ribs in separating *Fucus evanescens* from *Fucus inflatus* Vahl. The considerable formæ of and the distinction between *Fucus evanescens* and *Fucus inflatus* have been repeatedly discussed, but I can not find any reliable statement which clearly differentiates the two. A study of the herbarium specimens labelled with either of the two specific names would probably prove the ambiguity of the distinguishing characters. I have stood on the vast field of *Fucus evanescens* at Juan de Fuca Strait, Vancouver Isl., B. C.; and also on that at Kataoka Bay, Shimushu Island in the Kurile group. Although I am not wholly convinced, still the two collections made at those places have strengthened my inclination to agree with Strömpfelt,¹⁾ who included under the single species *Fucus evanescens* everything reported under the names *Fucus inflatus*, *F. edentatus* and *F. furcatus*. I am not, however, inclined at present to give any judgment on the matter as I have not yet visited a *Fucus* reef in the north Atlantic.

Localities : Osatsube, Oshima Prov. (H. S. A.); Mororan, Iburi Prov. (H. S. A.); Urakawa, Hidaka Prov. (H. S. A.); Esashi, Kitami Prov. (H. S. A.); Kushiro (T. KAWAKAMI)(!); Nemuro(!); Rubetsu(!), Ittokappu Bay(!), Etorofu Isl.

Fucus filiformis Gmel. f. *Pyglaisei* J. Ag.

DE TONI: Phyc. Jap. Nov. p. 48.—OKAM.: Enumer. Alg. of Jap. p. 137.
 = *Fucus leptophyllus* Kütz.: Tab. Phyc. X. p. 6. Taf. 12. fig. IV.—
 DECKIE: Alg. Jap. in Journ. Linn. Soc., Botany. Vol. XV.
 p. 450.

¹⁾ STRÖMPFELT: Om Algvegetation vid Islands Kuster, p. 35.

I have not seen any specimen of this species collected in Japan. Its occurrence on our coast has been reported by DICKIE but it is extremely doubtful to me. The upper portion of a sterile specimen of *Halysieris prolifera* OKAM. or of *Carpomitra Cabrerae* KÜTZ.—both occurring within our boundaries—has some apparent likeness to the species in question.

Locality : “Osima Harbour” (DICKIE).

PELVETIA.

Pelvetia Wrightii (HARV.) emend.

Plate I. Fig. 4-5.

HARVEY¹⁾ established two new species of *Fucus* from the specimens collected by CHARLES WRIGHT during the North Pacific Exploring Expedition of the American Navy. They were published with diagnosis only. As the definitions were rather briefly given, there arose some confusion in the attempts of later algologists to identify the species.

One of the species, *Fucus Wrightii*, was unanimously acknowledged by Japanese algologists; but the other, *Fucus Babingtonii* has been regarded as problematical by them. By the kindness of Prof. E. P. WRIGHT of Trinity College, Dublin, I was so fortunate as to get a set of fine photographs of the original specimens of *Fucus Babingtonii*. As a result of a study of the photographs when compared with the rich collection of the specimens in the herbarium of the Sapporo Agricultural College, I was able to satisfactorily identify the species. The two species described by HARVEY, however, are by no means fixed species but rather are different forms of one and the same species. Added to them we

1) HARVEY: Characters of New alge, p. 328-329.

have a third form more or less well defined, which will be remarked upon with the others below.

f. typica form. nov. Plate I. Fig. 4.

Diagnosis. Frondes lato-lineari complanata decomposita dichotoma ramosissima; vesiculis normaliter nullis; receptaculis lanceolatis compresso-turgidis terminalibus.

= *Fucus Wrightii* HARV.: Charact. of New Alg. p. 328.—DE TONI: Syll. Alg. III. p. 209.—*Id.*: Phyc. Jap. Nov. p. 48.

= *Pelvetia Wrightii* OKAM.: Enumer. Alg. of Jap. p. 138.—YENDO: Prelim. List of Jap. Fuc. p. 151.

The original diagnosis of *Fucus Wrightii* was based on a sterile specimen so that a little additional description will not be superfluous.

The frond is tereto-compressed, linear, decomposito-dichotomously branched, with the axils generally acute. The stem is subcylindrical and extremely short, measuring hardly one centimeter in length. It starts from the top of a comparatively small disc-shaped root. Occasionally it bifurcates into two branches before attaining a perceptible length, thus giving the appearance of two fronds starting from the same root. A frond, when fully grown, attains 3 feet in length with copious fastigate branches. The internodal segments are linear varying from 2 cm. to 10 cm. in length, more or less broadened upward, and with no sort of midrib. The sterile terminal segments are linear, truncated or bifurcated at the apices, each pair being parallel. Receptacles are limited to the terminal segments of the branches. They are mostly simple but frequently are bifurcated with wide angles. While yet very young they are flat and lanceolate but gradually swell up, at the same time increasing in general size. The plant is hermaphrodite and antheridia and oogonia are found in the same conceptacle. The conceptacles have bushy hairs which extrude from the mouth.

The typical plant has no true vesicles. But a few blister-like elevations are often met with in an upper branchlet or below a dividing point. In such cases they extend throughout the whole diameter of the segments concerned and are ovate or much elongated. This character is seldom met with in those specimens which were collected in the vicinity and southward of the Tsugaru Strait (Pl. I. fig. 4. a); but in those from colder parts, the ampulation becomes much more frequent, tending to a fixed character, and suggests gradual inclination to the next forma.

f. Babingtonii form. nov.

Diagnosis. Fronde angustiore compresso-plana decomposite dichotoma fastigiata; vesiculis oblongis compressis in ramis superioribus infra axillas immersis; receptaculis linearibus terminalibus complanatis simplicibus vel furcatis.

=*Fucus Babingtonii* HARV.: Charact. of New Alg. p. 329.

=*Pelvetia Babingtonii* DE TOXI: Syll. Alg. III. p. 216.—*Id.*: Phyc. Jap. Nov. p. 48.

The present forma differs from the preceding in having the vesicles constant. The vesicles are oblongo-linear, situated below the bifurcating points, and having diameters slightly larger than the breadth of the segment in which they are found. In the dried specimens they are apt to be over-looked owing to the collapse of the elevated surfaces. The plants which come under this category attain, as far as I can ascertain, hardly two feet in total length. Even the largest of the specimens is much inferior in size to the type specimen.

Fucus Babingtonii has been assigned by HARVEY to the coast of Simoda as well as to that of Hong-kong. It is beyond doubt that there is some mistake concerning the localities. The present forma and its sisters are found exclusively in the colder

seas and never come down so far south as the coast of Simoda washed by the warm Japan current. The plant which Dr. OKAMURA identified with HARVEY's species and distributed in the "Algæ Japonicæ Exsiccatae" No. 37, is limited to the warm part of Japan. But this is quite a distinct plant, being described in the present paper under the name of *Ishige Okamurai*. The Hongkong specimen, (if any plant of such form as is referable to the forma here described occur there), may probably be the same as *Ishige Okamurai*. But in the herbarium of Trinity College the specimen is lacking and I am unable to enter into any discussion of it.

This forma is more common in the middle part of Hokkaido; and in its characters gradually approaches *f. typica* on one side and *f. japonica* on the other, as we trace it westward and eastwards respectively. Details relating to this circumstance will be given in later paragraphs.

f. japonica form. nov. Plate I. Fig. 5.

Diagnosis. Fronde angustiore compresso-plana decomposite dichotoma fastigiata; vesiculis oblongis vel bilobis in ramis superioribus infra axillas inflatis; receptaculis linearibus truncatis terminalibus complanatis simplicibus vel fureatis.

= *Pelvetia japonica* YENDO.: Prelim. List of Jap. Fuc. p. 151.

The frond of this forma is thinner and narrower than that of *f. typica* and more resembles *f. Babingtonii* in this respect. The vesicles are oblongo-obovate, with a diameter sometimes more than twice as broad as the segment and considerably swollen on both surfaces so that they show a remarkable appearance in the dried specimens. They are, as a rule, found at the terminal portions of the upper segments, the inflation very often running into the upper two segments. Receptacles are linear,

obtuse or truncated at the apices. They are transformed from the terminal segments of the branches. In the majority of cases a small but remarkable vesicle is found at the point of meeting of the two adjacent fertile segments, giving to the receptacles the appearance of having started from the top of the vesicle.

Remark on the affinity and relation to other species. The three formæ above mentioned undoubtedly belong to one species. On the southern end of Hokkaido as well as on the Pacific side of northern Honshū we find *f. typica* only. But as we proceed northward, the chance of meeting *f. Babingtonii* increases; and in the north-eastern parts of Hokkaido *f. japonica* predominates.

The fronds of *f. typica* attain the largest size with proportionally thick segments. In some segments the breadth measures one centimeter, while in the other two it seldom exceeds half a centimeter. The high tide forms of *f. japonica* are indistinguishable from the young shoots of *f. typica* and the forms intermediate between these two formæ exhibit various modifications of *f. Babingtonii*.

The material from which HARVEY described *Fucus Wrightii* was sterile and the exact systematic position of the species has hitherto been in doubt. DE TOXI¹⁾ suspected it to belong to *Ascophyllum*, while he transferred *Fucus Babingtonii* to the genus *Pelvetia*. The vesicles, however, of *Fucus Wrightii*, or *Pelvetia Wrightii f. typica* as it is here called, are never normal and hence the reference of the plant to *Ascophyllum* is not acceptable.

On examining the conceptacles of *f. typica* and *f. japonica* I was able to ascertain that each oogonium contained two oospores, and that the essential characters of the reproductive organs proved

1) Syll. Alg. III. p. 209.

it to be *Pelvetia*. The two oospores, however, different from those observed in the other species of *Pelvetia*, resulted from a longitudinal partition of the mother cell. Very often the two oospores were obliquely situated in an oogonium but those in serial disposition were exceedingly rare. This character would not be important enough to warrant a claim for a new generic position for the species but must be included under the genus *Pelvetia* with the additional note to the generic definition that in certain members the spore-mother-cells are divided by a longitudinal partition.

HARVEY¹⁾ mentions, though with some doubt, a plant under the name *Fucus furcatus*, in the list of plants collected by Dr. LYALL at Esquimalt, Vancouver Island, B.C. He remarks some difficulty in referring his plant to that species and states that it scarcely differs from *Fucus Wrightii* of Japan. In 1901, I visited the "Minnesota Seaside Station" which stands on the west coast of the same island. On the rocks above high water mark, irrigated occasionally by the spray, I found a plant which bears a close resemblance to the dwarfed forms of our *Pelvetia Wrightii*. I had little doubt that it was the plant HARVEY meant in the above cited lines. SETCHELL and GARDNER²⁾ seem to think that HARVEY's plant probably belonged to a form of *Fucus inflatus*.

On comparing the high tide forms of *Pelvetia Wrightii* f. *typica* with the specimens collected by myself on Vancouver Island I find very little difference between them. Ours, however, are more yellowish when fresh and somewhat thinner than the Canadian plant. It is possible that specific differences between them may be found.

1) HARVEY: List of Plants collected by Dr. LYALL. (Journ. Linn. Soc. VI. p. 163).

2) SETCHELL and GARDNER: Algae of N. W. Amer. p. 280.

In the Minnesota Botanical Studies, Ser. III. Part 1, HOLTZ describes a plant under the name *Pelvetia fastigiata*, collected at the Seaside Station. The illustration of its habit (Pl. VII.) proves it to be of the same species as the plant that I collected there. The photograph of an isolated plant, though differing slightly from the Californian forms, shows the characters of *Pelvetia fastigiata*. It is somewhat broader than the high tide forms of *Pelvetia Wrightii* *f. typica*. The oogonia studied by HOLTZ prove the plant to belong to *Pelvetia*; and when I examined the receptacles of the fresh material of the Canadian form at the Station I also clearly observed the two parted oogonia. There can be no doubt that the plant described by HOLTZ is of the same species as that which I have compared to a high tide form of our *f. typica*; and that it is a form, if not the type, of *Pelvetia fastigiata*.

On the other hand, there is some similarity between the sterile specimens of *Fucus furcatus* *f. distichus* and the Canadian form—the reason, probably, why HARVEY thought the plant might be *Fucus furcatus*.

Summing up the above considerations I may conclude that there are close relationships between *Pelvetia Wrightii*, (especially *f. typica*) and *Pelvetia fastigiata*: that these are distinguishable from each other in their low tide forms only: that the sterile specimens of the two species found above the high water marks are scarcely distinguishable: and lastly that *Fucus furcatus* *f. distichus* has some external resemblance to the dwarfed forms of these two species.

Localities: *f. typica*; Matsushima, Rikuzen Prov. (OKAMURA); Kesenuma, Rikuchū Prov. (OKAMURA); Shimofuro (!), Shiranuka (!), Mutsu Prov.; Hakodate (!) (WRIGHT, HARVEY)

(H. S. A.); Hiura, Zenigamezawa, Oshima Prov. (H. H. F.); Shoya, Abuta, Urakawa, Cape Erimo, Hidaka Prov. (H. H. F.); Rishiri Isl. (!), Sawaki, Esashi, Rebunshiri, Abashiri, Shiretoko, Kitami Prov. (H. H. F.); Otaru (!); Rubetsu (!), Hitokappu Bay (!), Etorofu Isl.; Nemuro (!).

f. Babingtonii; Todohokke (H. S. A.), Osatsube, Hiura, (H. H. F.), Oshima Prov.; Mororan, Tomakomai, Iburi Prov. (H. H. F.) (H. S. A.); Shoya, Shitsukari, Saruru, Shamani, Hidaka Prov. (H. H. F.); Shakubetsu, Kushiro Prov. (H. H. F.) (H. S. A.); Shibetoro, Etorofu Isl. (H. H. F.); Abashiri (H. S. A.), Sawaki, (H. H. F.), Kitami Prov.

f. japonica; Osatsube, Numajiri, Oshima Prov. (H. H. F.); Mororan, Iburi Prov. (H. A. F.); Tomakomai, Hidaka Prov. (H. H. F.); Shari-utoro, Moyoro, Mombetsu, Kitami Prov. (H. H. F.); Nemuro (!) (H. H. F.); Rubetsu (!), Hitokappu Bay (!), Etorofu Isl.

CYSTOSEIRA Ag.

Cystoseira articulata J. Ag.

Spec. I. p. 216.—OKAM.: List of Alg. Coll. in Carol. and Austr. p. 82. (Bot. Mag. Tokyo, No. 209).

=*Hormophysa articulata* Kütz.: Tab. Phyc. X. p. 22. Taf. 61.

A specimen collected by Dr. K. MIYAKE is preserved in the herbarium of the Science College of Tokyo. On examination I found it satisfactorily referable to the species mentioned. For a full account of the generic position of the plant, see OKAMURA's paper, l. c.

Locality: Yonabara, Loochoo (K. MIYAKE, H. SC. COLL.).

Cystoseira triquetra J. Ag.

Spec. I. p. 215.—MARTENS: Preus. Exped. Tange. p. 115.—OKAM.: Enumer. Alg. of Jap. p. 141.

MARTENS reported a fragment of the present species floating on the Pacific Ocean near Japan. OKAMURA mentions this species in his Enumeration of Algae of Japan, l. c. but without any comment.

Locality : Japan (MARTENS); Loochoo (KUROIWA, OKAMURA).

Cystoseira Sonderi PICC.

Nuove Alg. Vettor Pisani, p. 23, No. 60.—DE TOXI: Syll. Alg. III, p. 175.

=*Treptacantha Sonderi* Kütz.: Tab. Phyc. X, p. 11, Taf. 28, fig. III.

—DICKIE: Alg. of Jap. in Journ. of Linn. Soc., Bot. Vol. XV, p. 450.

I have not seen any specimen of this species collected within our boundaries. DICKIE may have been in error.

Locality : “Osima Harbour” (MOSELEY, DICKIE).

? *Cystoseira specigera* AG.

Spec. p. 64.—DICKIE: Alg. of Jap. in Journ. of Linn. Soc., Bot. Vol. XV, p. 450.

DICKIE doubtfully mentions the plant without any comment. DE TOXI¹⁾ has already questioned the occurrence of the present species in Japan.

CYSTOPHYLLUM J. AG.

Cystophyllum geminatum J. Ag.

Spec. I, p. 232.—DE TOXI: Syll. Alg. III, p. 156.—OKAM.: Enumer. Alg. of Jap. p. 139.—SEICH. et GARD.: Alg. of N. W. Amer. p. 285.

=*Cystoseira geminata* AG.: System. p. 286.

=*Sirophysalis geminata* Kütz.: Spec. p. 602.

=*Cystoseira thyrsigera* Post. et RUPR.: Ill. Alg. taf. 38, fig. 1.—RUPR.: Tange des Ochot. Meer. p. 347.

=*Cystophyllum Lepidium* HARV.: List of Plants Vancouver. p. 163.

—DE TOXI: Syll. Alg. III, p. 156.—SAUNDERS: Alg. from

1) DE TOXI: Phyc. Jap. Nov. p. 47.

Harr. Alaska. Exp. p. 432.—COLLINS, HOLDEN and SETCHEL: Phyc. Bor. Amer. No. XLVII.—TILDEN: Amer. Alg. Cent. III. No. 232.

= *Cystoseira Lepidium* RUPR.: Tange des Ochot. Meer. p. 347.—KÜTZ.: Tab. Phyc. X. Taf. 52. fig. 1.

= *Cystoseira hypocarpa* KÜTZ.: Tab. Phyc. X. Taf. 52. fig. 2.—DE TONI: Syll. Alg. III. p. 175.

Remark on the synonymy. *Cystophyllum Lepidium* HARV. and *Cystophyllum hypocarpa* KÜTZ. are not well marked with *Cystophyllum geminatum* J. AG. This circumstance has been noted by former writers, who, however, mentioned the three pseudo-species separately. SETCHELL and GARDNER¹⁾ united them into one under the single species *Cystophyllum geminatum* J. AG. which is highly preferable.

RUPRECHT²⁾ says that *Cystophyllum Lepidium* does not occur in the north Pacific, and that the specimen in MERTEN'S herbarium bearing that name and labelled "Insul. Kurile" seems to have been collected at Saghalin Island. The specimens, however, in our hands are from the southern Kuriles. In Etorofu Island, where I collected the plant, it is especially common along the northern side, often covering an extensive area of rocks in the sublitoral region and not infrequently occurring mixed with *Fucus evanescens* in the litoral region.

Localities: Rubetsu(!), Shana (H. H. F.), Etorofu Isl. (OKAMURA). Uruppu Isl. (H. H. F.).

Cystophyllum crassipes J. Ag.

Plate II. Fig. 9-12.

Spec. I. p. 232.—DE TONI: Syll. Alg. III. p. 155.—*Id.*: Phyc. Jap. Nov. p. 46.

1) SETCHELL and GARDNER: l. c. p. 286.

2) RUPRECHT: Tange. p. 347.

- =*Fucus crassipes* MERT.: in TURN. Hist. Fuc. Vol. II. p. 154. Tab. 131.
=*Cystoscira crassipes* AG.: Spec. p. 69.—*Id.*: System. p. 286.
=*Sirophysalis crassipes* KÜTZ.: Spec. p. 602.—*Id.*: Tab. Phyc. X. Taf. 56. fig. 1.—MARTENS: Preus. Exped. Tange. p. 128.
=*Sirophysalis kakiloides* KÜTZ.: Tab. Phyc. X. Taf. 56. fig. 2.
? =*Fucus kakiloides* MERT. mscr? (*sec.* DE TONI: Syll. Alg. 1. c.).

I have seen no authentic specimen of the present species. But judging from the illustrations delineated by TURNER in Hist. Fuc., l. c. and by KÜTZING in Tab. Phyc., l. c., I venture to refer the specimens from eastern Hokkaido to this species.

Description of the species. In a fully grown individual, the frond attains 3–6 feet in total height, solitarily attached to the substratum by a hemispherical or subconical disc-shaped root. The stem is simple, stout and cylindrical, measuring about half a centimeter in diameter. It gradually diminishes in thickness upwards and sends out several branches in all directions, which further divide into fastigate branchlets. The principal branches at the lower parts of the axial stem are similar in appearance to the latter, but are somewhat more slender with more abundant scars of old branchlets.

In a young or average plant the axial stem barely reaches a few inches in height but has several branches already of considerable length at its upper portion. These branches have their basal regions incrassated into fusiform stems. I shall call these branches “fusiform branches” for convenience sake. While the plants are yet very young, the incrassation of the stems is very conspicuous and the future indefinite branches and branchlets appear as several short, cylindrical but recurved processes at the upper ends, as well as on the swollen sides, of the fusiform bodies. Cf. Pl. II. fig. 13. Each apical process of these fusiform bodies elongates further into an axial member and the processes

at the upper portion mostly elongate into lateral branches; while those on the swollen side develop into subordinate fusiform stems of similar appearance.

The stems of the fusiform branches are smooth, cylindrical or subterete, and measure about 2 mm. in diameter above the incrassated portion. Lateral branches are given out in all directions, apparently pinnately ramose in the pressed specimens. Some of them in the upper portions are geminate but by no means of specific importance.

The lower lateral branchlets of the fusiform branches are generally entirely wanting in vesicles. They often attain 13–16 cm. in length, the diameter of the stems being 1.5 mm. or less. The leaves at the basal portions of these branchlets are narrowly linear, 2–3 cm. in length and 1.5–3.0 mm. in breadth, pointed above, and tapering below into flat stipes. They are ribless and entire. The upper leaves become narrower by degrees and divide decompoundly pinnately or apparently sympodially. The terminal ones are hair-like and less ramose.

The lateral branchlets found in the middle portions of the fusiform branches are decompoundly pinnate and are vesiculiferous at their basal parts with or without the receptacles on the terminal regions. The uppermost branchlets are generally destitute of vesicles and each ultimate segment ends in a receptacle.

Vesicles are spherico-ellipsoidal with a long, flat stalk at the base, and are mucronated or awned at the top. Some of them are found with one or more minor vesicles in succession on the top. Each two successive vesicles are sharply and distinctly separated one from another by a short and delicate link. This character is especially important in distinguishing

a sterile form of the present species from the one next mentioned.

Receptacles are simple lanceoid-cylindrical, solitarily situated at the terminal points of the sympodially divided ramulets.

Localities: Sawara, Oshima Prov. (H. H. F.); Mororan, (H. S. A.), Abuta, (H. H. F.), Iburi Prov.; Onnebetsu, Kitami Prov. (H. H. F.); Nemuro (!).

Cystophyllum hakodatense sp. nov.

Plate II. Fig. 13-15.

= *Cystophyllum* ? *hakodatense* YENDO.: Prelim. List of Fucac. of Japan. p. 152.

= *Cystophyllum crassipes* OKAM.: (nec J. Ag.). Enumer. of Alg. of Japan. p. 139. *excl. syn.*

Diagnosis. Radice scutelata, hemisphaerico-elevata; caule gracili, cylindraceo, undique ramis egredientibus; ramis a basi incrassatis, fusiformi-elongatis, sursum complanatis, filiformibus, inermibus, quoquoversum ramulis egredientibus; foliis inferioribus anguste lineari-lanceolatis, superioribus filiformibus pinnatim divaricatis; vesiculis ellipsoideis solitariis vel concatenatis, longe stipitatis, apice obtusis vel in ramulis fructiferis abeuntibus; receptaculis cylindraceis verrucosis longe pedicelatis.

Description of the species. A well grown plant of the present species measures 5-6 feet in length, attached to the substratum by a circular disc which is slightly elevated at the top. Pl. II. fig. 5 shows a young shoot just starting out. In this sort of plant the stem at the basal region is smooth and cylindrical, not exceeding a few inches in length. The primary stem is subclavate, with a number of fusiform, approximate branches near the top as well as around the swollen portion. The morphological characters of these fusiform branches are identical with those described under the preceding species.

The lateral branchlets which start from the lower portions of the fusiform branches are more or less thick and robust,

hardly exceeding 10 cm. in length. They are decomponently alternately divided, with the lower laciniae terete filiform; the upper ones may develop into ordinary leaves. As a rule, they are sterile and not provided with vesicles. Occasionally, however, the apex of a leaf is inflated into an ovate mucronate vesicle. The branchlets from the middle and the upper portions develop further and constitute the principal parts of the frond. They are decomponently subpinnately ramose with leaves or sterile ramules at the base; the ultimate segments become vesiculiferous and, when mature, are fertile. The leaves are linear-lanceolate, acuminate above, and taper downwards into a short, flat stipe: they are ribless, entire, and destitute of cryptostomata.

Vesicles are ellipsoidal or ovate, occasionally fusiform. They are sometimes solitary but 2-5 or more of them are found in a moniliform series at the terminal portion of a vegetative segment. The constrictions between two successive vesicles are loose and seldom stalk-like. The inferior end of the lowermost vesicle of a series tapers downwards into a long filiform stipe, and from the upper end of the uppermost vesicle, a racemose receptacular ramulet rises. Each receptacle is lanceoid-cylindrical, verruculose, acuminate above and with a filiform stipe below.

Remark on the affinity to other species. There are six species hitherto reported from the north Pacific Ocean, which have some relation to the present species, viz:—*Cystophyllum crassipes* J. AG., *Cystophyllum geminatum* J. AG., *Cystophyllum Lepidium* HARV., *Cystophyllum filifolium* J. AG., *Cystoseira spicigera* AG., and *Cystoseira hypocarpa* KÜTZ. Among these six species, *Cystoseira hypocarpa* KÜTZ. is probably synonymous with *Cystophyllum Lepidium* HARV. as DE TONI¹⁾ has already pointed out; and *Cystoseira*

1) DE TONI: Syll. Alg. III. p. 175.

spicigera Ag. is a doubtful plant being described from an undoubtedly incomplete specimen: and lastly, *Cystophyllum Lepidium* HARV. has no well marked character to separate it from *Cystophyllum geminatum* J. AG. The remaining species *Cystophyllum crassipes* J. AG. and *Cystophyllum filifolium* J. AG. have been assigned to Japan and are more closely related to the plant here described than to any of the others.

Cystophyllum crassipes apparently stands close to the present species especially when we compare the sterile specimens of both. But the relative positions of the vesicles and receptacles readily distinguish the two species. *Cystophyllum filifolium* J. AG. was formerly reckoned under the genus *Cystoseira* by C. AGARDH. This circumstance at first led me to identify our plant with that species. But the characters of the vesicles and receptacles in the diagnosis of *Cystophyllum filifolium* J. AG. are rather nearer to *Cystophyllum crassipes* J. AG. than to the present species.

So far as our present researches extend we can not find any other species than *Cystophyllum crassipes* and the present one, that approaches the description of *Cystophyllum filifolium* J. AG. It may be permissible to say that the last mentioned species may be identical with either of the two species mentioned. At present, however, I must leave J. AGARDH's species in doubt, with the hope that some one who has an opportunity of examining the original specimen, will carefully compare it with the two species described in this paper.

Remark on the generic position of the present species. So long as the definition of the genus *Cystoseira* remains as it is now, the plant here described ought to be counted under that genus. In the preliminary list of the *Fuaceae* of Japan, I¹⁾

1) YENDO: l. c. p. 152.

hesitatingly referred this species to *Cystophyllum*. No one will doubt that there is a very close relationship between the present species and *Cystophyllum crassipes* and that it may be found that these two do not belong to different genera.

In such species as *Cystoseira ericoides* AG., *Cystoseira Myrica* J. AG., *Cystoseira fibrosa* AG., etc., the vesicles are not limited to the final division of the ramulets, and certain portions of vegetative organs are generally found above a vesicle. But in *Cystoseira Osmundacea* AG., *Cystoseira feniculacea* GREV., *Cystoseira squarrosa* KÜTZ., etc., the case, as in the present species, is different: the vesicles are always on the terminal division of the vegetative organs, and only the receptacles or the receptacular branchlets may be found above a vesicle. In *Cystophyllum geminatum* the relative positions of receptacles and vesicles are somewhat indeterminate: in most cases the receptacles are above the vesicles but not infrequently a vesicle may be found at the apex of a receptacle. Cf. also KÜTZING'S Tab. Phyc. X. Taf. 52 fig. 2. under *Cystoseira hypocarpa*.

I propose the following key to distinguish *Cystoseira* from *Cystophyllum*:—

Cystoseira: vesicles not restricted to the final divisions of the vegetative organ.

Cystophyllum: vesicles restricted to the final divisions of the vegetative organ; only the receptacles or receptacular ramulets may be above the vesicles.

In accordance therewith *Cystophyllum hakodatense* may without impropriety be assigned to the genus *Cystophyllum* and other species such as *Cystoseira Osmundacea* AG., *Cystoseira feniculacea* AG., *Cystoseira squarrosa* DE NOT. etc., should be transferred to that genus.

Localities : Iwaki Prov. (OKAMURA); Rikuchū Prov. (OKAMURA); Shimofuro, Mutsu Prov. (!); Hakodate (!) Esashi, Oshima Prov. (H. H. F.); Cape Raiden (H. H. F.), Yoichi (H. H. F.), Takashima (H. S. A.), Sukuzushi (H. S. A.), Zenibako (H. S. A.), Shiribeshi Prov.; Atsuta (H. S. A.), Mashike (H. H. F.), Ishikari Prov.; Rumoi (H. H. F.), Chikubetsu (H. H. F.), Onishika (H. S. A.), Teshio Prov.; Rishiri Island (!), Abashiri (H. H. F.) (H. S. A.), Kitami Prov.; Nemuro Harbour (!), Tomoshiri (H. H. F.), Nemuro Prov.; Kushiro (T. KAWAKAMI) (!) (H. S. A.); Shoya (H. H. F.) (H. S. A.), Horoizumi (H. H. F.), Urakawa (H. H. F.), Hidaka Prov.; Tomakomai (H. S. A.), Mororan (H. H. F.), Iburi Prov.

Cystophyllum sisymbrioides J. AG.

Plate III. Fig. 1-6.

- Spec. I. p. 234. *excl. syn.*—DE TONI: Syll. Alg. III. p. 158. *excl. syn.*
 —*Id.*: Phyc. Jap. Nov. p. 47.—OKAM.: Enumer. Alg. of Jap. p. 140.
 = *Fucus Myagroides* TURN.: Hist. Fuc. Vol. II. p. 28. Tab. 83.
 = *Fucus sisymbrioides* TURN.: Hist. Fuc. Vol. II. p. 150. Tab. 179.
 = *Spongocarpus sisymbrioides* KÜTZ.: Phyc. Gen. p. 365.—*Id.*: Spec. Alg. p. 632.—*Id.*: Tab. Phyc. X. Taf. 91. fig. 1.—SURING.: Alg. Jap. p. 26.—MARTENS: Preus. Exped. Tange. p. 116.
 = *Sargassum Myagroides* AG.: Spec. p. 25.—O'KUNTZE: Revisio Gen. Plant. III. 2. p. 427.
 = *Sargassum sisymbrioides* AG.: System. p. 307.—O'KUNTZE: Revisio Gen. Plant. III. 2. 427 *excl. syn.*
 = *Sargassum filicinum sisymbrioides* O'KUNTZE: Revisio Sarg. p. 215.
 = *Spongocarpus siliculosus* SOND.: in KÜTZ. Tab. Phyc. X. Taf. 91. fig. 2.
 = *Myagropsis Camelina* KÜTZ.: Ueber d. Eigent. (Bot. Zeitg. 1843) p. 57.—*Id.*: Spec. Alg. p. 634.—*Id.*: Tab. Phyc. X. Taf. 92. fig. 1.—*Id.*: Phyc. Gen. p. 368.—MARTENS: Preus. Exped. Tange. p. 130.

This is one of the most common algæ along nearly the whole of our coast. As the frond is apt to vary in form the exact

character of the species was not satisfactorily advertised. The following remarks may add something to the present knowledge of the plant.

Description of the species. Roots are disc-shaped, occasionally attaining 7 cm. in diameter, flat on the lower surface and subhemispherical on the upper, from which a stout cylindrical, rugose stem arises. At the lower portion of the stem a number of decomponently pinnated branches are given off patently. The upper terminal point of the stem is truncated and complanated, with short "anlage" of the branchlets on both sides. (Cf. Pl. III. fig. 7 b. under *Cystophyllum Turneri*). The lateral branches are distichously pinnately disposed on the principal branches and are exceedingly approximate. The principal branches are, in a manner, a sort of "Kurztrieb." The pinnation of an order is always in a plane at right angles to the plane in which the pinnation of the next order lies.

The lower parts of the stems of the lateral branches are smooth and subcompressed, elliptical in cross section. Near the insertion points they are much thickened, forming subfusiform or not infrequently angulate bases. When a well grown plant is uprooted and beaten upon the shore for many days, the lateral branches wear away from the point just above the swollen region. The result is a robust twig with coarse dentation along both sides of each branch (fig. 8.).

The lateral branches are transformed either into the definite branchlets (leaves) or into the filiform stems of the indefinite branchlets. The leaves are linear 1.5–2 mm. wide and 10–20 mm. long, occasionally measuring 30–35 mm. Well developed ones are pinnately sected or, more strictly speaking, sympodially divided. A slightly elevated midrib traverses the whole length of each leaf

with the lateral veins running into the segments. The basal part of each leaf is more or less constricted to form a short cylindrical petiole. The leaves are either directly inserted in the "Kurztrieb" disposed in the manner explained above, or they are alternately pinnately arranged along the margins of subterete, filiform indefinite branchlets. One or more of the lateral segments of a leaf are often transformed into vesicles.

Well grown lateral branches often measure 6.5 feet in length. The stems are terete, compressed with round edges. Each gives off minor ramules from its edges in a distichous, alternate and pinnate manner. These ramules are simple or decompound and have vesicles at the lower part and receptacles at the upper; in a younger ramule, the vesicles only. Both vesicles and receptacles are alternately pinnately arranged.

Vesicles vary in their form according to their position in a frond. Those which are transformed from the lateral segments of a leaf, and usually found at the basal regions of a frond, are ellipsoidal, 6–8 mm. in major axis and 4–5 mm. in minor axis, slightly narrowed downwards, each having a short stalk, and coronated with a narrow, linear, costated leaflet at the apex. As we trace them upwards, they become much elongated, diminishing in diameter and finally becoming spindle-shape. Such vesicles have stalks often as long as their length and the corona frequently long and setaceous.

Receptacles are racemosely arranged at the upper part of a ramulet, the terminal one being the largest. They are elongated conical or cylindrical, attenuated above and abruptly ending at the base in a comparatively long filiform stalk. The receptacles of both sexes have the same appearance, except that the female receptacles mostly have a darker colour.

Remark on the synonymy. The present species is readily recognized by its general habit. The colour, the texture and the external appearance of the upper portions of the sterile fronds remind us of *Desmarestia aculeata* as has been noted by former algologists.¹⁾ Without seeing the fertile branches one is led to place the species under the *Phyllotricha* J. Ag. not however without difficulty. C. AGARDH²⁾ once actually referred the plant to *Sargassum*.

O'KUNTZE³⁾ has dwelt on the opinion that the species in question should be classified under the genus *Sargassum*. The generic conception of *Sargassum* given by him in his papers differs widely from that of recent authors. As far as the Japanese species of *Sargassum* and *Cystophyllum* are concerned, I can not fully concur in the specific disposition of KUNTZE. There is no doubt that he is trying to disarrange the system of *Sargassum* after a study of fragmental herbarium specimens.

Myagropsis Camelina KÜTZ. was first described in "Botanische Zeitung," 1843, p. 57., from a specimen collected by TILESIIUS in Japan. J. AGARDH⁴⁾ referred both it and *Myagropsis Turneri* KÜTZ. to his *Sargassum sisymbrioides* remarking that the former two have been described from the upper portions of the latter. KÜTZING⁵⁾ insisted upon his opinion and illustrated the so called inferior part of *Myagropsis Camelina*, at the same time, criticising sharply J. AGARDH's reference.

I took particular care in trying to settle the problem. There is no doubt that *Spongocarpus siliculosus* SOXN. is identical with

1) Cf. DE TONI: Syll. Alg. III. p. 158.

2) C. AGARDH: System. p. 307.

3) O'KUNTZE: Revisio Gen. Plant. III, 2. p. 427; *Id.*: Revisio von Sargassum. p. 215.

4) J. AGARDH: Spec. I. p. 234.

5) KÜTZING: Tab. Phyc. X. p. 32. Taf. 92. fig. 1.

Cystophyllum sisymbrioides. I have found, however, a plant which is much more applicable to *Cystophyllum* (*Myagropsis*) *Turneri* than to *Cystophyllum sisymbrioides*. The detail will be given under the next species. As for *Myagropsis Camelina* I have little doubt, judging from the descriptions and figures given by KÜTZING, l. c., that it belongs to the present species.

In defining *Myagropsis Camelina*, KÜTZING¹⁾ says that the stem is “zusammengedrückt, dreikantig” and that the branchlet “flach dreikantig.” He further observes that the stem is “hie und da mit spitzigen und hakenförmigen Dornen besetzt,” and the branchlets “an den Kanten mit zweispalten, entfernt stehenden, sehr kleinen Dörnchen besetzt.” These statements are evidently induced from the scars of the dropped lateral branchlets, leaves, or vesicles. The size of the vesicles cannot be a specific character in this case. I have many specimens of *Cystophyllum sisymbrioides* which have in their basal portions more roundish vesicles than KÜTZING has figured under *Myagropsis Camelina*.

Localities: Nagato Prov. (!); Izumo Prov. (OKAMURA); Tango Prov. (!); Wakasa Prov. (R. TSUGE) (!); Noto Prov. (OKAMURA); Echigo Prov. (!); Sado Prov. (!); Rikuzen Prov. (!); Hitachi Prov. (!); Boshū Prov. (!); Misaki (!), Enoshima (!), Sagami Prov.; Izu Prov. (!); Shima Prov. (!); Awa Prov. (!); Bungo Prov. (!); Nagasaki (HORN, TURNER).

Cystophyllum Turneri nov. nom.

Plate III. Fig. 7–11.

= *Myagropsis Turneri* Kütz.: Ueber d. Eigent. (Bot. Zeitg. 1843) p. 57. excl. syn.—*Id.*: Spec. Alg. p. 634.—*Id.*: Phyc. Gen. p. 368.—*Id.*: Tab. Phyc. X. p. 32. Taf. 92. fig. 2.—MARTENS: Preuss. Exped. Tange. p. 130.

1) KÜTZING: Ueber die Eigentümlichkeit. (Bot. Zeitg. 1843 s. 57).

Description of the species. I have not yet seen an authentic specimen of *Myagropsis Turneri* Kütz. But the plant here treated answers to the descriptions and illustration of KÜTZING's species in many points.

KÜTZING referred TURNER's *Fucus Myagroides* to his genus *Myagropsis*, calling it *Myagropsis Turneri*. After a careful examination of the material at hand, I found that TURNER's species should be amalgamated with *Cystophyllum sisymbrioides* as had been done by J. AGARDH¹⁾; and that KÜTZING's species accorded fairly well with another plant found in several parts of Japan. This plant has several well marked characters and deserves a specific rank. Hence the name *Cystophyllum Turneri* (Kütz.)

The relative dispositions of the branches and branchlets in the present species are identical with the preceding. But the branchlets are generally less approximate in this species, and the thickening of the basal parts of the stems is less conspicuous and even quite negligible. The stems of the branchlets are filiform, more slender and compressed than in the preceding species, but occasionally angulate at the thickened portions.

The leaves are very narrow, hardly attaining 1.5 mm. in breadth but frequently measuring 12 cm. in length. They are alternately pinnately divided, with the segments patent and distant, and with a breadth nearly equal to that in the axial part. The midrib is distinct, and traverses the whole length of the leaf, running into the segments up to their apices.

The vesicles on the lower portions of the branchlets are subspherical, 3.5 mm. in length and 3 mm. in diameter, with a stalk slightly shorter than the length of the vesicles, and coro-

1) J. AGARDH, Spec. Alg. I. p. 234.

nated with simple or often bifurcated, long, linear-spathulate, subcostated leaflets. Those in the lower portions of the minor ramulets are mostly spherical 1.5–2 mm. in diameter with long stalks and simple setaceous crown leaflets. Very young vesicles, usually found at the upper parts of the minor ramulets are slightly ovate or pyriform. Two or more spherical vesicles are often disposed in a series with filiform links, and coronated on the terminal one (fig. 10).

Receptacles are cylindrical, acuminate above, racemously arranged at the upper part of a ramulet. In the majority of cases only the terminal one develops, the rest being abortive. Hence the receptacles are apparently solitary and terminal on the ramulets.

The largest specimen I have seen measured 3 feet in total length.

In other respects it is similar to *Cystophyllum sisymbrioides*.

Localities: Boshū Prov. (H.S.A.); Misaki, Sagami Prov. (!); Sanuki Prov. (!); Chikuzen Prov. (M. YANO) (!).

Cystophyllum caespitosum sp. nov.

Plate III. Fig. 12–13.

Diagnosis. Radice hemisphaerico-scutelata, caule simplici, teretiusculo, ramis undique egredientibus; ramis filiformibus, compressis, inermibus, decomposite pinnatim ramulosis, pinnis e margine distichis; vesiculis in petiolo ipsis nunc æquale nunc brevior ellipsoideis, folio simplici vel furcato coronatis; receptaculis apice ramulorum racemosis cylindraceis; caulibus foliisque minute glandulosis.

Description of the species. The present species is easily recognized by the general appearance and the extreme delicacy of every part of the frond. The indefinite branches at the lower portions of a frond attain greater length than those at the upper, so that the entire plant is densely caespitose and fastigiate.

The lateral branchlets on the lower indefinite branches measure generally 20–30 cm. in length when fully grown. Their stems are delicate and filiform, about $\frac{3}{4}$ mm. wide, issuing subordinate ramulets in an alternately pinnate manner. The ramulets are further divided in a similar manner, and their basal segments may be transformed into vesicles and the upper segments into receptacles. The vesicles are small, ovate, with a short stipe at the base and a simple or bifurcated leaflet at the apex. No ribs are found on the leaves, as the latter seem too narrow to admit them. All parts of the frond except the old and basal portions are provided with small but obvious cryptostomata.

The mode of ramification, the disposition of the receptacles and other essential characters of the present species, except the points remarked above, are similar to the preceding two species. What has been stated about them may in general be applied to the species here described.

Localities : Echigo Prov. (!); Ugo Prov. (!).

TURBINARA LAMX.

Turbinaria ornata J. Ag.

Spec. I. p. 266.—OKAM.: Enumer. Alg. of Jap. p. 141.

I have not seen a specimen of this species.

Localities : Ishigaki-jima, Loochoo (OKAMURA); Bonin Isl. (OKAMURA).

Turbinaria trialata Kütz.

Tab. Phyc. X. p. 24. Taf. 67.—BARTON: Syst. Struct. Acc. of *Turbinaria* p. 218.—DE TONI: Syll. Alg. III. p. 127.

= *Turbinaria vulgaris* var. *trialata* J. Ag.: Spec. I. p. 268.

= *Turbinaria heterophylla* Kütz.: Tab. Phyc. X. Taf. 69. fig. 1.

A single but fertile specimen, collected by Dr. K. MIYAKE in Loochoo, is kept in the herbarium of the Science College of the Tokyo Imperial University. It accords very well with the descriptions of the above mentioned species and especially with the illustrations of *Turbinaria trialata* var. *capensis* KÜTZ. in Tab. Phyc. l. c.

Locality: Tomari, Loochoo (MIYAKE, II. SC. COLL.).

Turbinaria (?) *fusiformis* YENDO.

Plate IV. Fig. I-7.

Prelim. List of Fuc. Jap. p. 153.

=*Cystophyllum fusiforme* HARV.: Charact. of New Alg. p. 328.—DE TONI: Syll. Alg. III. p. 159.—*Id.*: Phyc. Jap. Nov. p. 47.—OKAM.: Alg. Exsic. Jap. No. 36.—*Id.*: Enumer. Alg. of Japan. p. 141.

f. clavigera YENDO. l. c. Plate IV. Fig. 7.

=*Cystophyllum fusiforme* β *clavigerum* HARV.: l. c.

Remark on the species and the forma: The present species was described by HARVEY under the genus *Cystophyllum* from the material collected by CHARLES WRIGHT at Shimoda and Hakodate. Since that time no one has given any further information respecting the plant except that DE TONI repeated the original diagnosis in his works above cited. HARVEY's specimen was sterile; and as the species was established on incomplete dried specimens there are some points misrepresented in the original diagnosis. The following remarks may not be unnecessary for a full knowledge of the species.

The root is a small holdfast, with the rhizines robust and cylindrical, ca. 1 mm. in diameter. Frequently some of the rhizine elongate horizontally like a stolon, giving off several minute processes from the under sides.

The stem is erect, cylindrical, usually branching at a short distance from the holdfast. A few radical leaves are found below or near the diverging point of the stem. These leaves are borne by very young individuals only, and seem to drop off at an early stage. They are flat but thick and succulent, yellowish brown, and slightly elevated along the median line; some are very small, ovate or clavate, hardly measuring 1 cm. in length; some, however, grow to be as large as 4 cm. by 1 cm., and are linear-spathulate, more or less tapering upwards, ending in a round apex, with a short cylindrical petiole. I have seen them frequently with undulating or even coarsely dentated margins (fig. 2 and 3a, b).

The rami, as they are called, on the young and short branches vary in shape according, it seems to me, to the locality. In the plants found in the northern seas, they are short and clavate with the apical portion inflated into a pyriform "vesicle." In those of the southern seas the "vesicles" are mostly mucronated or slightly tapering upward and seldom become fusiform. The plants commonly found along the coast of middle and southern Japan, and as far as Korea, have all the "rami" several inches long, solid, cylindrical with equal diameter throughout nearly the whole length; and frequently some of the "rami" are elongated, clavate, complanated above and sparingly dentated. In such forms the ramuli on the lateral branches are fusiform and inflated.

Generally speaking, the plants from cold seas are rich in the clavate "rami"; while in those from warmer regions the "rami" on the principal members are mostly filiform, the fusiform rami being limited to the lateral branches. The former coincide with the definition of *β. clavigerum* HARV. But it is

an invalid form and a number of intermediate forms between both extremes may be met with.

Branchlets are axillary. They are for the most part stunted and are beset with several ramuli in a spiral arrangement. The result is the presence of subfasciculate bunches at the axils. The ramuli are always an inflated fusiform however the fulcrant "rami" may vary in their shape. Hence those plants which have the filiform and cylindrical "rami" assume a very widely spread and slender appearance (fig. 2), while those in which the pyriform "rami" predominate, have a dense and robust appearance (fig. 2.).

Receptacles are smooth, cylindrical clavate, round at the apex, and have very short stalks. As a rule, 3-5 or more of them are found forming a cluster on an inconspicuous stem, directly on the axil of a "ramus" or of a ramulus of the fertile branches.

Remark on the systematic position of the species. *Cystophyllum fusiforme* was established by HARVEY, as above noted, from sterile specimens. So far as I have been able to ascertain no one has ever described its receptacles. In spite of the abundance of the sterile individuals, the receptaculiferous plants are rather rare. The plants attain their utmost luxuriance at the end of April and most of them are driven away from the substratum before they produce the reproductive organs. Some of the plants, which have passed a summer, and dropped most of the "rami" from the lower and middle portions of the fronds continue their development late into the autumn; and those in quiet coves frequently reach 6-8 feet in total height at the end of the following March. The receptacles are found in June and July. They are sometimes met with on individuals a few inches in height which had evidently germinated the previous autumn, or sometimes on the two-year old fronds.

A close observation of the receptacles suggests the impropriety of assigning the species to the genus *Cystophyllum* as has been acknowledged. The receptacles are unquestionably axillary, however much the fulcrant leaves may vary in their shape.

As may be understood from the above remarks the fulcrant leaves or the "rami" may vary in shape to a considerable degree. If these cylindrical "rami" have been considered as a modification of the ordinary leaves of *Sargassum*, we shall find a remarkable relationship of this species to that genus. On the other hand, if the vesiculation of the clavate "rami" has been taken as an important character of the species, the plant must be counted as a member of, or at least standing very close to, the genus *Turbinaria*. The only difficulty in so disposing of it is that the species hitherto placed under *Turbinaria* have winged and trumpet-shaped "vesicles," while in our species they are smooth and ovate or fusiform. The foliaceous leaves at the base of the young plants of this species seem at first to justify assigning it to *Sargassum*. But according to J. AGARDH,¹⁾ KUTZING,²⁾ *et al.*, the leaves at the basal portions of the *Turbinaria* species are also often filiform or dichotomously divided. Most species of *Sargassum* have disc-shaped roots, and all of *Turbinaria*, like the plant under consideration have ramose holdfasts. The two genera, *Sargassum* and *Turbinaria*, stand very close to each other in regard to the relative positions of the vegetative and reproductive organs. The only radical distinction between them is that the latter genus has nearly all the "rami" transformed into vesicles, characteristic of the genus; while in the former the differentiation of the "rami" into leaves and vesicles is

1) Species I. p. 265.

2) Tab. Phyc. X. Taf. 67-68.

highly developed. Our species shows the character of both genera at once, if indeed it is not an intermediate form.

To propose a new generic position for such a plant as this, which stands between two genera so closely allied as *Turbinaria* and *Sargassum* would be unacceptable. I provisionally mention the problematic species under *Turbinaria*, expecting that a closer study of the phylogeny of the two genera will probably settle the legitimacy or illegitimacy of assigning it as I have done.

Localities: Nagasaki (H. SC. COLL.); Mogi (H. SC. COLL.); Higo Prov. (!); Tsushima Prov. (Y. YABE); Fusan, Korea (H. YABE); Tango Prov. (OKAMURA); Rikuchū (?) (OKAMURA); Hakodate (?) (OKAMURA); Kazusa Prov. (!); Boshū (!); Sagami Prov. (!); Izu Prov. (!) (WRIGHT, HARVEY); Numazu, Izu Prov. (H. S. A.); Ise Prov. (OKAMURA); Shima Prov. (!); Kii Prov. (!); Awa Prov. (!); Tosa Prov. (H. S. A.); Kagoshima (OKAMURA).

f. clavigera: Tsugaru Str. (WRIGHT, HARVEY); Toppu, Zenigamezawa, Fukuyama, Hakodate (!) (H. S. A.), Oshima Prov.; Rikuchū Prov. (!) (H. S. A.); Rikuzen Prov. (!); Eno-ura, (H. SC. COLL.), Shimoda (!), Izu Prov.

COCCOPHORA GREV.

Coccophora Langsdorffii GREV.

Plate V.

Alg. Brit. p. XXXIV.—KÜTZ.: Spec. Alg. p. 635.—*Id.*: Tab. Phyc. XI. Taf. 45. fig. 2.—J. AG.: Spec. I. p. 250.—SMITH: in MURR'S. Phyc. Mem. II. p. 30. t. IX.—DE TONI: Syll. Alg. III. p. 184.—*Id.*: Phyc. Jap. Nov. p. 48.—MARTENS: Preuss. Exped. Tange. p. 130.—YENDO: On *Cocc. Langs.* p. 137.

=*Fucus Langsdorffii* TURN.: Hist. Fuc. Vol. III. p. 76. Tab. 165.

=*Fucus Tilesii* AG.: Dec. No. 1.

=*Cystoseira Tilesii* AG.: Spec. p. 78.—*Id.*: System. p. 291.

- = *Coccophora phyllamphora* J. AG.: Spec. I. p. 250.—MARTENS: Preus. Exped. Tange, p. 130.—KÜTZING: Tab. Phyc. XI. Taf. 48. fig. 1.—*Id.*: Spec. Alg. p. 636.—DE TOXI: Syll. Alg. III. p. 185.—*Id.*: Phyc. Jap. Nov. p. 48.
 = *Cystoseira phyllamphora* AG.: Spec. p. 79.—*Id.*: System. p. 291.—*Id.*: Icon. Alg. Ined. Tab. IV.

Description of the species. Judging from the references hitherto accessible to me, no complete frond of the present plant seems to have reached the algologists. They have unanimously remarked that the conceptacles are found in the walls of the vesicles. The present writer was so fortunate as to get many complete specimens at Hakodate and actually to observe the habit in the same locality.

A well grown individual measures 40–50 cm. in total length arising at the base from a knotty stump, which is firmly attached to the substratum. From the surface of the stump there start out several shoots which soon branch into several stems. The bases of the shoots are mostly swollen into rugose knots which give a rough aspect to the primary stump. In an old plant the shoots often fall off, leaving the basal knots on the surface of the primary stump; the latter thus becoming much more knotty. These shoots correspond morphologically to the indefinite branches of *Sargassum*.

There are two distinct forms of shoots. One of these satisfactorily answers to the descriptions and figures of *Coccophora phyllamphora* J. AG., and the other to those of *Coccophora Langsdorfi* GREV. I shall call the former the *Phyllamphora* form for convenience sake. This is nothing but a young part of the frond and is always found un-branched and sterile. The latter, called for convenience, LANGSDORF'S form, as has been well figured by TURNER and by SMITH, is simple and straight,

and gives out numerous receptaculiferous branches in all directions. Frequently one or more branches of the *Phyllamphora* form are found in the places usually occupied by the receptaculiferous branches.

The apical portions of the axial stems of LANGSDORF'S form are generally rubbed off. As a rule, the scale-like leaves are entirely wanting on the axial stems throughout the whole length. For a few inches from the basal point the stems are naked, but with subprominent scars of the fallen leaves.

Of the receptaculiferous lateral branches, SMITH¹⁾ gave a full description and beautiful illustration. He seems to have doubted the existence of the small bulb at the base of each lateral branch as described by TURNER. I also was not able to verify any such character as TURNER described and illustrated.

The stems of the lateral receptaculiferous branches are more slender than the axial member and are covered with scale-like leaves spirally arranged with a divergence of $\frac{2}{3}$. These leaves are approximate below and gradually separate toward the apex of the stems. The lower leaves are very small, hardly exceeding 1.5 mm. in length and 0.5 mm. in the broadest part, sessile, entire and tapering upward; the upper ones become gently elongated often attaining 10 mm., equally sessile and tapering with but one or two obtuse teeth on the lower margins. In the apical portions of the stems, the leaves are replaced by berry-like hollow receptacles, each borne on a short stalk. The uppermost receptacle on each branch, as a rule, is the largest.

The stems of the *Phyllamphora* form are as thick as the axial stem of LANGSDORF'S form, and are similarly covered with scale-like leaves in similar arrangement. The leaves are, however,

1) SMITH: in MURRAY'S *Phyc. Mem.* Part II. Pl. IX.

much further apart. Those on the middle portions of the stems measure 2-3 cm. in length, and 1.-1.5 mm. in breadth, gradually tapering upwards. The dentation is limited to the basal portion which is now broadened into stipule-like appendages; and finally divides into distichously alternately pinnate leaves, each segment equaling the main part in breadth.

Near the middle portions of the simple or parted leaves, the vesicles are found. They are elliptical or subspindle shaped, generally only one to a leaf, but often two or more in the same leaf. When found in the parted leaf they are usually situated near the parting point. If they are found just at the point, the part above the vesicle has the appearance of a furcated corona.

In some fully matured specimens of the *Phyllamphora* form an embryonal stage of the lateral branch was found at each axil of the leaves. It can be demonstrated that these leaves fall off before the lateral branches come to maturity. No specimen was found with a leaf remaining undetached at the base of a receptaculiferous branch.

Remarks on the synonymy and the systematic position of the plant. *Coccophora phyllamphora* J. AG., as has been stated above, is a pseudo-species described from a sterile branch of *Coccophora Langsdorffii* GREV. As far as I could judge from the habit of the plant the sterile simple branches begin to give rise to the lateral fertile branches early in the summer or late in the spring. The latter attain their maturity in the spring of the next year, the new phyllamphora forms appearing until then. Thus the basal stump is evidently perennial.

It is curious that no one has ever detected the relation between the two forms. Sterile and fertile branches have stood

as separate species for nearly a half century. OKAMURA is the only one, as far as my references extend, who has touched on this problem. He¹⁾ noted that *Coccophora phyllamphora* might possibly be a special modification of its fellow species. But ceased to pursue the subject further.

As LANGSDORF's form was taken as the complete or nearly complete frond, the hollow receptacles were thought to serve at the same time as vesicles. This consideration resulted in an awkward misrepresentation in the systematic disposition.

The fact that the lateral branches are axillary, and that the vesicles and receptacles are developed into special organs places the present plant near *Sargassum*; but both in general appearance and in minute points, there is hardly any correspondence with any species of *Sargassum*. The decaying away of the vegetative portions, which bear the vesicles, and the succeeding growth of the reproductive branches are especially characteristic. We find some species of *Sargassum* whose vegetative branches in greater part disappear before the maturity of the receptacles. As regards the lateral branch, arising from an axil of a leaf, with receptacles at the apical portions, and some with vegetative leaves on the lower portions, we can find some similarity in *Sargassum* only.

The essential morphological difference between *Sargassum* and *Coccophora* lies in the fact that the vesicles and the receptacles may occur in the same definite branch in the former, while they are in separate ones in the latter.

The amputation of the receptacles seem to be the result of physiological necessity, for the vesicles are already absent when the reproductive organs have reached maturity. In this respect

1) OKAMURA: Enumer. of Alg. Jap. p. 138.

the character may be considered under a conception similar to that of the receptacles of the *Hormophysa*.

Localities: Hakodate (!); Mutsu Prov. (!); Noto Prov. (OKAMURA); Echigo Prov. (OKAMURA).

Coccophora (?) Imperata YENDO.

Plate IV. Fig. 8-12.

Prelim. List of Jap. Fuc. p. 154.

Diagnosis. Radice primordiale ignota, plantae adultiores nodoso-prostrata, caulibus communibus confluenti, ramis erectis sursum exeuntibus; ramis cylindraceis inermibus ad basim mox intumescuntibus, spiraliter ramulis egredientibus; ramulis brevissimis spiraliter foliis gerentibus; foliis basalibus sessilibus, stipulatis, filiformibus, dichotome divaricatis, minute glandulosis, ramulorum sessilibus imbricatis; vesiculis receptaculisque ignotis.

Description of the species. The fronds are apparently multicapital, arising from a rugose knotty prostrate stump. Morphologically speaking, the stump, as in *Coccophora Lungsdorfi*, is a dwarfed stem, and the erect stems upon it correspond to the principal branches of *Cystophyllum* and *Sargassum*. The stems are cylindrical, 20-30 cm. high, more or less abruptly thickened at the very base, with short stunted ramules subregularly spirally disposed above: angle of divergence ca. $\frac{1}{3}$.

Ramules are beset with filiform elongated leaves at the base and with subulate scale-like leaves above, in the same disposition as the ramules on a stem. The filiform leaves divide dichotomously once or twice with wide axils, with a few elevated cryptostomata on the surface; the base of a leaf is generally abruptly expanded and often stipule-like. The scale-like ones are obcuneate, broadened downward, concave inside, and longitudinally ridged outside (fig. 12).

Receptacle and vesicle unknown.

Remark on affinity. A good number of the specimens of the present plant were sent from the Marine Experiment Station of Akita Prefecture. But none of them was either fertile or vesiculiferous. The exact systematic position can not be ascertained at present. The scale-like leaves, their disposition on the ramules and the general characters of the root, suggest a close affinity to *Coccophora Langsdorffii*, from which, however, it may at once be separated by the dotted filiform leaves.

If referable to *Coccophora*, which is highly probable, the specimens at hand are a vegetative form of the plant, being parallel to the Phyllamphora stage of *Coccophora Langsdorffii*. The lateral ramules with the scale-like leaflets may grow to be the receptaculiferous branches. Further discussion is reserved until we shall have been able to examine a fertile specimen.

The densely foliferous ramules at the upper portions of the stem remind us of the paniculate inflorescence of *Imperata*. Hence the specific name.

Locality: Ugo Prov. (!).

SARGASSUM Ag.

PHYLLOTRICHIA J. Ag.

Sargassum pituliferum Ag.

Plate VI. Fig. 1-7.

Spec. p. 27.—J. Ag.: Spec. I. p. 289.—HARLOT: Alg. d. Yokosk. p. 218.—SURINGAR: Alg. Jap. p. 25.—MARTENS: Preuss. Exped. Tangé. p. 116.—DE TONI: Syll. Alg. III. p. 17.—*Id.*: Phyc. Jap. Nov. p. 43.—OKAM.: Enumer. of Alg. of Jap. p. 143.

=*Fucus pilulifer* TURN.: Hist. Fuc. Vol. I. Tab. 65.

=*Fucus microceratius* TURN.: Hist. Fuc. Vol. II. p. 153. Tab. 130.

=*Sargassum microceratium* AG.: Dec. No. 33.—J. AG.: Anal. Alg. Cont. III. p. 59.

=*Myagropsis microceratia* KÜTZ.: Tab. Phyc. X. Taf. 94.

Description of the species. Frond attains 2–4.5 feet in height with a knotty, rugose, disc-shape root at the base. Generally several shoots start from the surface of the same root, giving the appearance of a multicipital frond. A primary shoot is nothing but a simple lanceolate or linear leaf attached to the surface of a circular disc by a very short petiole. It gradually elongates and divides decomponently pinnately, with the margin entire; an immersed midrib traverses the whole length of the lamina and a series of cryptostomata is found on each side of the latter. The pinnæ are 1.5–2.0mm. wide and the entire length of a leaf measures 5–6 cm.

The axial part of a primary shoot develops to form the main stem of a frond, thickening simultaneously into a compressed or ancipitous rachis. The lower portion of the stem has several leaves arising alternately from the ancipitous edges. These leaves are essentially similar to the primary shoots in every respect. In an old stem, these lower leaves are generally worn off, leaving conical scars at the points of insertion. The stem in the upper portions is subterete, with rounded margin, measuring 1.5–2.0mm. in breadth. The fulcrant leaves in the upper portions are fili-form, subterete, pinnately divided or apparently dichotomous, or sometimes simple, with the apices of the segments sharply pointed. No distinct midrib is found in the upper leaves which have cryptostomata on the margins.

Vesicles are spherical, without cryptostomata, ending abruptly in a slender stipe as long or even twice as long as the diameter

of the vesicles. The apices of the vesicles are absolutely round and smooth. A vesicle is evidently transformed from the apical portion of a segment of a leaf, and is often found at a terminal end of the bifurcated leaflets.

Receptacles are ramose, spirally arranged on the ultimate ramulets. They are cylindrical, more or less tapering upwards, with verruculose surface in the matured specimens. They are 2–3 mm. long with slender stalks of about half their length. A fulcrant leaflet is found at the base of a fertile ramulet but no branchlet exists at the insertion point of a receptacle.

var. pinnatifolium var. nov. Plate VI. fig. 8–11.

= *Sargassum pinnatifolium* Ag.: System. p. 303.—Kütz.: Tab. Phyc. XI. Taf. 33.—DICKIE: Alg. Jap. in Journ. Linn. Soc. Bot. Vol. XV. p. 449.—MARTENS: Preus. Exped. Tange. p. 116.—YENDO: Prelim. List of Jap. Fuc. p. 154.

= *Fucus pinnatifolius* Ag.: Alg. Dec. No. 3.—*Id.*: in Act. Holm. 1815. Tab. 5.

= *Sargassum Henslowianum* var. *pinnatifolium* J. Ag.: Spec. Sarg. p. 121.—DE TONI: Syll. Alg. III. p. 109.—*Ill.*: Phyc. Jap. Nov. p. 45.—OKAM.: Enumer. Alg. of Jap. p. 159.

Description of the variety. The essential characters of the fronds of the present variety are similar to those of the type, except in a few points. I am not acquainted with the primary stage of the frond. Judging, however, from the youngest plants at hand, it is easily seen that both the type and the variety have similar aspects in the primary stage. The basal leaves of the well grown individuals are robust in texture and darker in colour: hence the cryptostomata are usually undetectable in the basal leaves. The leaves and stems are generally much narrower in the type than in the variety.

Vesicles are comparatively small, measuring 2.5–3 mm. in diameter, pyriform, not coronated, attenuated below into a stipe

of equal or double the length of the vesicle. They are found at the lower portions of the fertile ramules, often assuming the position of branchlets. The shape of the vesicles is an important point in distinguishing practically the variety from the type. It must be kept in mind, however, that an intermediate form is sometimes met with.

Receptacles are cylindrical, simple or often divided, verruculose on the surface, and with a short stipe. They are racemously disposed on a fertile ramule. A linear-lanceolate subulate leaflet is found at the base of a lower receptacle, but is usually wanting in the upper ones.

Remark on the affinity and the synonymy. The type and the variety are so closely related that it is often hard to distinguish them by mere description. In general aspect, however, they are always quite different from each other and one never fails to separate them at a glance although he will often meet with plants of an intermediate character.

A plant bearing the name *Sargassum piluliferum* Ag. is distributed in COLLINS, HOLDEN and SETCHELL's Phyc. Bor.-Amer. No. 537, and also in FARLOW, ANDERSON and EATON's Alg. Exsic. Amer. Bor. No. 102. On comparing it with our specimens I do not hesitate to say that the American plant and our own belong to different species, or at least different varieties. The diagnosis of *Sargassum piluliferum* given by J. AGARDH in his former works accords very well with our plants: but the description of the same species in his Spec. Sarg. Austr. relates much more closely to the American plant than to ours.

The present species was first reported from Japan as collected by TILESITUS and described by TURNER in 1808. The specimen seems to have been incomplete and the specific definition was

rather inadequate and ambiguous. Afterwards an allied plant was found on the Californian coast and was referred by FARLOW to the same species. As far as I could judge, the American plant differs from ours in having terete verrucose stems, while ours has compressed and smooth ones: the leaves are generally smaller and more delicate, the receptacles much shorter and more approximate in the American plant than in the Japanese. J. AGARDH omits to mention the present species in Anal. Alg. Cont. III. It is rather remarkable that the species which was originally established on Japanese material should be referred to an American plant and its occurrence in the mother country neglected.

The definitions of *Sargassum pinnatifolium* by AGARDH¹⁾ and by KÜTZING²⁾ are at once applicable to *Sargassum piluliferum*. The figures, however, delineated by the latter in his Tab. Phyc., l. c., suggest the plant that I mention here in varietal rank. If the determination by the present writer has been correctly done, the plant is by no means a valid species but merely a variety of *Sargassum piluliferum* AG.

J. AGARDH³⁾ refers *Sargassum pinnatifolium* to a variety of *Sargassum Henslowianum*. Had all the fulcrant leaves in the illustration of the latter species been removed, it might have assumed a shape nearly similar to that of our variety, the young fertile ramulets of *Sargassum Henslowianum* corresponding, in the illustration, to the much divided upper leaves of this variety. I am compelled to suspect that J. AGARDH compared the two plants, by their illustrations, in some such way as has been

1) AGARDH: System. l. c.

2) KÜTZING: Spec. Alg. p. 616.

3) J. AGARDH: Spec. Sarg. p. 121.

suggested: otherwise, we can hardly imagine any affinity between the two. He,¹⁾ however, remarked that if a complete specimen of *Sargassum Henslowianum* var. *pinnatifolium* J. Ag. had been examined, his variety might be found to belong to the *Dimorphæ*: and he²⁾ entirely disregarded that variety in his later work.

SURINGAR mentions *Sargassum piluliferum* f. *capillaris* SUR. in *Algae Japonicæ* p. 25. as being distinguished from the type by having "foliis superioribus capillaribus enerviis." But as above stated, the upper leaves in the adults of the present and of the next species, generally lack the midrib and this character is never formal.

Fucus microceratius TURN. it would seem had better be amalgamated with the present species. The only difficulty in doing so is that the figure illustrated in *Hist. Fuc.*, l. c., has the vesicles mucronated or apiculated. But TURNER in describing the species says that the vesicles are spherical and externally smooth. In *Tab. Phyc.*, l. c., KÜTZING delineates all the vesicles with round apices. These facts strengthen my belief that TURNER's species and its derivatives should be placed in a position synonymous with the present species.

It is to be noted here that a sterile, non-vesiculiferous form of *Cystophyllum Turneri* is often difficult to distinguish from a similar form of this species.

Localities: Nagasaki (H.S.COLL.); Chikuzen Prov. (M. YANO (!); Tsushima Prov. (H.S.A.); Nagato Prov. (!); Osumi Prov. (H.S.A.); Tosa Prov. (H. YAMAMOTO (!); Sanuki Prov. (!); Kii Prov. (H.S.A.); Shima Prov. (!); Mikawa Prov. (!); Sagami Prov. (!);

1) *Spec. Alg.* I. p. 290; *Sarg. Austr.* p. 122.

2) *Anal. Alg.*, Cont. III. p. 49 *et seq.*

Boshū Prov. (!); Kazusa Prov. (!); "Elsewhere on the coast of the Japan Sea and the Pacific Ocean" (OKAMURA).

var. pinnatifolium: Oshima, Kii Prov. (MOSELEY, DICKIE); Akashi Channel (MOSELEY, DICKIE); Japan (TILESUS); Mikawa Prov. (!); Noto Prov. (!); Tango Prov. (!).

Sargassum setaceum YENDO.

Plate VII. Fig. 5-7.

Prelim. List of Jap. Fuc. p. 154.

Diagnosis. Radice scutelata complanata, caule communi breve cylindraceo, mox fastigiato ramoso, ramis teretibus sursum compressis, subtortilis, pinnato-ramulosis, ramulis sæpe geminatis; foliis inferioribus anguste linearibus decomposite pinnatis, laciniis lineari-lanceolatis, evanescente costatis, superioribus filiformibus decomposite dichotomis, laciniis longissimis setaceis ecostatis, sparsim glandulosis, terminalibus simplicibus setaceis; vesiculis inferioribus sphaerico-obovatis, muticis, in petiolo ipsas æquante, superioribus mediisque glandulosis, in inferiore ramulorum parte solitariis; receptaculis cylindraceis breve stipitatis, apice ramulorum racemosis.

Description of the species. A well grown plant attains a height of 3-4 feet with copious lateral branches. The root is disc-shaped, flat and comparatively small, hardly 1.5 cm. in diameter. Often two or more shoots are found starting from a common disc. The stem is short and cylindrical, 1-2 cm. in length, and a few mm. in diameter. It soon gives rise to several fastigiato branches which are practically the principal members of the frond. The stems of these branches are cylindrical or terete, gradually compressed above and loosely twisted, pinnately ramose. The basal leaves on the old branches are complanated, thin and coriaceous, decompositely alternately divided. Each segment is linear-lanceolate, entire, with an obscure rib running nearly the whole length, and without cryptostomata. The upper

leaves are in like manner decompoundly pinnately divided, but the segments are thick, filiform and ribless, cartilaginous in substance and frosted with conspicuous cryptostomata on the surface. The young branches are morphologically similar to the basal leaves and may further develop into long branches by the thickening and elongating of the axial segment.

One or two lateral branches start out from each axil of the middle and the upper leaves. The lower lateral branches measure 20 cm. or more, the lowest being the longest. The leaves on the branches are essentially like the fulcrant leaves but the number of segments gradually decreases. The leaflets on the terminal portions of the ramulets are mostly simple and setaceous.

Vesicles are sphaerico-obovate, round at the apices, and have stipes as long as the vesicles. Those in the lower portions of the fronds lack the cryptostomata but those in the upper are evidently spotted with conspicuous ones. They are mostly found solitary near the insertion points of the branches or branchlets.

Fertile ramulets are found at the axil of the simple setaceous leaflets in the terminal portions of the lateral branchlets. The receptacles are cylindrical, somewhat pointed above, verruculose on the surface, and with a short stipe.

Remark on the affinity. The present plant exhibits close similarity to *Sargassum piluliferum* and its variety. On the other hand, it has no less resemblance to the plant reported from the Californian coast under the name *Sargassum piluliferum*. This species, however, is, in the well grown individuals, easily distinguished from the others by its having ribless, filiform leaves.

Locality: Kashiwajima, Tosa Prov. (!).

SCHIZOPHYCUS J. AG.

Sargassum pinnatifidum HARV. mut. str.

Plate VII. Fig. 1-3.

Charact. of New Alg. p. 327.—? J. AG.: Anal. Alg. Cont. III. p. 50.
Diagnosis (emend.). Caule tereti sursum compressa, distiche pinnatim ramosis, ramis e margine egredientibus; foliis inferioribus approximatis, anguste linearibus, laciniis linearibus simplicibus vel pinnatifido-dichotomis, integris, costatis, superioribus linearibus, laciniis lineari-lanceolatis, argute serratis subsingula utrinque serie glandulosis; vesiculis ellipsoideis folio saepe bipartito serrato coronatis; receptaculis.....

Description of the species. There are three specimens of the present species which were collected by Dr. K. MIYAKE and are kept in the herbarium of the Science College of the Tokyo Imperial University. None of them have the basal part of the frond and they are all sterile. In the spring of 1904, I found several specimens at Misaki; and in the next year, I received a specimen of the same species for determination from the Hiroshima Higher Normal School. Unfortunately these were equally sterile and lacked the basal portions.

As far as the material shows, the axial stem is complanated with rounded edges and has short lateral branches from its margins. In some specimens a short spinous process was found at the edge of each internode in the lower portions. The lateral branches are disposed distichously pinnately with the internodal distance rarely exceeding one centimeter. The lower ones have the leaves on them very approximate and when they drop off, the scars give the stem a very rugose and prickly appearance. The leaves on these branches are narrow and linear, measuring 1-2 mm. in breadth and are subdichotomously furcated, or often simple. An immersed midrib traverses almost the entire length of the

lamina, running into each segment. The margin of the leaves usually has a few sharp dentations but often is quite entire. In one specimen collected at Misaki, all of the leaves were entire; while in another, the leaves on the basal portions were entire but those on the upper had become dentated. The total length of a leaf measures 3-5 cm. No cryptostoma were found on the leaves.

The leaves on the upper branches are thin and membranaceous. They are essentially similar to the lower ones in shape but attain a much larger size, often measuring 8 cm. in length, and 4 cm. in maximum breadth. They are occasionally decomponently pinnately sected and the margin is mostly dentated. In the specimen from the Hiroshima Higher Normal School the apices of the segments are obtuse but in the Loochoo specimens they are generally acute. The cryptostomata are small but evident, and are arranged in an irregular series on each side of the lamina.

Vesicles are usually found solitary at the base of the lateral branches or on the petiole of the fulcrant leaf of the upper portions of a frond. They are oblong or sometimes spherical, coronated with simple or bifurcated leaflets and with stipes shorter than their diameter, which varies from 3 to 5 mm.

Receptacles unknown.

Remark on Relation to other species. Judging from the photographs, the original specimens of *Sargassum pinnatifidum* HARV. were two different plants catalogued under the same name. One of them is evidently equal to *Sargassum patens* var. *Schizophylla*; and the other, an upper portion of the present species. HARVEY did not distinguish them as separate species, and the original diagnosis of *Sargassum pinnatifolium* seems to

relate more to *Sargassum patens* var. *Schizophylla* than to the present species. J. AGARDH mentions *Sargassum pinnatifidum* in Anal. Alg. l. c. I have not seen his specimen; but as far as I can judge from the description his plant is probably different from ours here described.

This species has some apparent resemblance to *Sargassum piluliferum* Ag. This is especially the case with the lower portions of a sterile specimen. But the latter species has the vesicles always round at the apices, while in the present species they are coronated with a simple or furcated leaflet, or at least they are mucronated. It has still more likeness to *Sargassum patens* var. *Schizophylla*, so much so that some fragmentary specimens of both species, especially when dried, can hardly be distinguished from one another. The present species, indeed, shows characters to some extent intermediate between the two species above mentioned. The short lateral branches with approximate leaves, however, may in many cases serve to distinguish the sterile specimens.

I am equally in doubt as to the propriety of mentioning this species under the subgenus *Schizophycus* J. Ag. although it undoubtedly stands nearer to *Sargassum patens* var. *Schizophylla* than to any others. The present arrangement is a provisional one until we shall have the good fortune of examining the embryonal stages of the frond.

Localities : Loochoo (WRIGHT, HARVEY); (K. MIYAKE) (!); Misaki (H.S.A.) (!); Shima Prov. (H. HIROSHIMA HIGH. NORM. SCH.) (!).

Sargassum patens Ag.

Plate VIII.

Ag.: Sp. p. 47.—*Id.*: System. p. 303.—J. Ag.: Spec. I. p. 288.—*Id.*: Spec. Sarg. p. 56.—*Id.*: Anal. Alg. Cont. III. p. 50.—DE TONI:

Syll. Alg. III. p. 19.—*Id.*: Phyc. Jap. Nov. p. 43.—HARBOT: Alg. de Yokosk. p. 218.

=*Sargassum Rodgersianum* HARV.: Charact. of New Alg. p. 327.

=*Fucus patens* AG.: in Act. Holm. 1815. p. 244.

=*Fucus pilulifer* 3 *major* TURN.: Hist. Fuc. Vol. I. p. 146.

=*Halochloa patens* KÜTZ.: Spec. Alg. p. 632.—*Id.*: Tab. Phyc. XI.

Taf. I. fig. 1.—MARTENS: Preus. Exped. Tange. p. 116.

=*Anthophycus japonicus* MART.: Preus. Exped. Tange. p. 115.

=*Carpophyllum?* *japonicum* DE TOXI: Phyc. Jap. Nov. p. 46.

Description of the species. The youngest plants of this species have a few basal leaves growing almost radially from the top of a disc-shaped root. The primary basal leaves are usually simple, elliptical or obovate, with a short flat petiole: but the successive upper ones become much longer, alternately lobed, with the lobes narrowed at the points of divergence and mostly elliptical in outline.

The younger basal leaves elongate further by apical growth adding a few lobes, as it were, successively above the older ones. When they have grown several inches in height, the upper lobes eventually become narrower and pinnately sected. Leaves in this stage are no longer leaves but branches, and the lobes are evidently the definite branches, i. e. the leaves. This manner of development is characteristic of *Phyllotricha* J. AG. and *Schizophycus* J. AG.

The leaves on the lower portions of the branches are sometimes simple and sometimes divided. The simple ones are linear-spathulate more or less narrowed upwards with the margins subentire or sparingly dentated: the base is very often oblique, terminating in a short petiole. The divided leaves usually diminish in breadth: the margins are mostly subentire but often roughly toothed.

The upper leaves on the stems become gradually narrower

and finally filiform; at first patent, but soon bent upward. They usually divide into a few segments, and those at the apical regions are mostly simple. Very often we find a simple leaf attaining 20 cm. in length.

The basal leaves—the young branches—as well as the leaves on the elongated stems are always flat on the same plane in which the flattened stem lies. This character distinguishes the plant readily from the other members of the *Bactrophycus* or *Eusargassum*. An elevated rib runs along the median of the leaf, sending out lateral costæ into the lobes if any. In the upper filiform leaves these costæ are not evident, especially in the dried material; but the cross section of leaves of this sort from a fresh specimen is elliptical, with the middle portion slightly elevated on both surfaces. Cryptostomata are always present along the edges of the upper leaves and stems. In the lower leaves, however, they are, as a rule, obscure.

Ramules are axillary. In the beginning they appear as short subcompressed processes starting from the upper margin of the petiole. Each process develops into a vesicle and a ramule starts from the basal point of the vesicular stalk. (Plate VIII. fig. 3, 5).

Vesicles are obovate or subspherical, with a complanated stalk nearly as long as the vesicle, and each crowned with a simple or pinnately divided filiform leaflet. In the upper vesicles several cryptostomata are found as elevated brown spots.

Receptacles are linear, simple or often divided, round at the apices, attenuated below, disposed on a short ramule in a distichously pinnate manner. Cryptostomata are also found on the receptacles.

var. *Schizophylla* YENDO. Plate IX. Fig. 1-3.

Prelim. List of Jap. Fuc. p. 155.

= *Halochloa Schizophylla* Kütz.: Ueber d. Eigent. (Bot. Zeitung 1843.)
s. 56.—*Id.*: Spec. Alg. p. 632.—*Id.*: Phyc. Gen. p. 367.—*Id.*:
Tab. Phyc. XI. Taf. I. fig. 2.

= *Sargassum pinnatifidum* HARV. p.p.: Charact. of New Alg. p. 327.—DE
TONI: Syll. Alg. III. p. 20.—J. AG.: Anal. Alg. Cont. III. p. 50.

Description of the variety. *Sargassum patens* AG. varies greatly according to the condition of the environment and the season; still, there is a distinct form found in the southern part of Japan. This form accords with the description and the illustration of *Halochloa Schizophylla* Kütz. It is, however, by no means a species, as we sometimes encounter a specimen which shows intermediate characters, especially when sterile.

The radical leaves of the variety are simple or pinnately lobed as in the type. They are, however, thin and membranaceous, beset with several irregular rows of inconspicuous cryptostomata; the margins of the simple leaves or the segments of the divided leaves are minutely dentated, and the axial laminae of the divided leaves are usually armed with a few sharp spinous processes on the margins. The lower fulcrant leaves are lobed into several lateral segments, each segment, as well as the axial lamina being irregularly but sharply serrated. Very frequently two vesicles are found serially connected, the upper one being crowned with a divided leaflet at the top. Occasionally one or two simple leaflets were found on a vesicle at some distance from the corona. (Pl. VIII. fig. 8).

The leaves on the upper portions are as in the type. In some dwarfed forms, however, they are often short and profusely ramose, apparently approaching certain leaves of *Sargassum pinnatifidum*. Some extreme forms show a resemblance to the lower

portions of *Sargassum piluliferum*. A specimen from Tsushima Island, preserved in the herbarium of the Sapporo Agricultural College, has the upper leaves almost capillaceous. KUNTZE¹⁾ notes that *Halochloa Schizophylla* is an abnormal young form of *Sargassum piluliferum*. This is probably derived from such partial similarity.

J. AGARDH, MARTENS and others agree in the opinion that *Halochloa Schizophylla* Kütz. is hardly separable from *Sargassum patens* AG. MARTENS²⁾ observes that the former is nothing but a young individual or a lower part of the latter species. As has been stated above, the difference between the type and the variety is already perceptible in the young shoots.

Remark on the synonymy. As has been stated in the preceding chapter, the original definition of *Sargassum pinnatifidum* given by HARVEY is satisfactorily applicable to *var. Schizophylla*. J. AGARDH³⁾ recognized the close affinity between HARVEY's species and *Sargassum patens* AG. He mentioned, however, *Sargassum pinnatifidum* HARV. as an independent species as it differed to some extent from the type form of *Sargassum patens* AG. It is much to be regretted that the eminent algologist did not happen to compare it with the variety.

Sargassum Rodgersianum is also a species established by HARVEY. The original diagnosis is so very brief that we can hardly grasp the exact character of his plant. J. AGARDH mentions the species in Anal. Alg. cont. III. p. 54. But judging from the remark made by him in that paper, and from the fact that he mentioned it under the subgenus *Bactrophycus* it is

1) KUNTZE: Revisio von Sarg. p. 227.

2) MARTENS: Preuss. Exped. Tange. p. 116.

3) Anal. Alg. Cont. III. p. 54.

beyond doubt that his plants were quite different from HARVEY'S. By the kindness of Prof. WRIGHT of Trinity College I was able to get the photograph of the original specimen of *Sargassum Rodgersianum*. The plant is nothing but a part of *S. patens* Ag. GRUNOW had recognized this when he revised HARVEY'S specimen, according to a letter from Prof. WRIGHT, and the label bearing the name *Sargassum Rodgersianum* HARV. is correctly amended.

Anthophycus japonicus is proposed by MARTENS in Preuss. Exped. Tange. p. 115. The diagnosis is not clear enough being in some respects applicable to *Sargassum Ringgoldianum* HARV. DE TOXI¹⁾ referred it doubtingly to the genus *Carpophyllum*. GOEBEL illustrates a plant in Biologische Schildringen p. 8. fig. 2. bearing the name of *Anthophycus japonicus* MART. The figure reveals nothing but an upper portion of a sterile frond of the typical form of the present species.

Localities: Nagasaki (KJELLMAN, J. AGARDH), Goto (KJELLMAN, J. AGARDH), Hizen Prov. (!); Tsushima Prov. (H.S.A.); Shimomoseki (KJELLMAN, J. AGARDH), Nagato Prov. (J. NIKAI) (!); Izumo Prov. (!); Iwami Prov. (!); Tango Prov. (!); Shimōsa Prov. (!); Boshū Prov. (!); Sagami Prov. (H.S.A.) (!); Shima Prov. (!); Kii Prov. (!); Awa Prov. (!); Tosa Prov. (H.S.A.); Sanuki Prov. (!); Aki Prov. (!); Bingo Prov. (!).

var. Schizophylla: Misaki (H.S.A.) (!); Kii Prov. (!); Awa Prov. (!); Higo Prov. (!); Hizen Prov. (!); Loochoo (OKAMURA), (WRIGHT, HARVEY); Tsushima (H.S.A.).

Sargassum toense YENDO.

Plate IX. Fig. 1-1.

Prelim. List of Jap. Fuc. p. 158.

Diagnosis. Radice scutelata compressa; caule communi brevissimo mox

1) Phyc. Jap. Nov. p. 46.

racemoso; ramis complanatis ancipitibus sursum teretibus, pinnatim ramulosis, pinnis e margine egredientibus; ramulis teretibus vel cylindraceis pinnatis; foliis verticalibus, linearilanceolatis basi constrictis, simplicibus vel pinnato-dichotomis costatis integerrimis vel crispato-dentatis, utrinque pluri-serie glandulosis; vesiculis sphaerico-ovatis, folio simplici vel furcato coronatis, glandulosis, in inferiore ramulorum parte solitariis; receptaculis subcylindraceis verruculosis in ramulo paniculatis.

Description of the species. The plant attains 3–5 feet in total length. The root is disc-shape of irregular outline, comparatively small in size. From the upper surface of the root several shoots often start off, each of which may ramify at a short distance from the base almost multicipitally. The primary shoot is complanated, linear-elongated, attenuated below into a short, terete stem, and alternately pinnately divided above. An immersed rib traverses the whole length of the axial segment and diverges into the lateral segments quite to the apices. Thus the primary shoot is very similar to that of *Sargassum patens*. But in the present species the axial segment is from the very beginning of its growth more stem-like. As the shoot grows further the axial segment becomes a stem with enormously prolonged internodes, but remaining flat, immersedly ribbed, and with ancipitous margins crispato-dentated. The lateral segments develop into simple, basal leaves which are narrowly lanceolate, attenuated upward, slightly ribbed, cryptostomated, and crisped or undulated in the margins. In some cases basal leaves measured 20 cm. in length and 1 cm. at the widest part (Pl. IX. fig. 4.).

The stem in the upper portions as well as in the lateral branches is no longer ancipitous but terete, with the fulcrant leaves at its compressed margins. Most of the fulcrant leaves are simple, linear-lanceolate, but often pinnately divided with narrow segments. Branches and branchlets start patently from the upper edge of the

petiole of the fulcrant leaves, as in the case of *Sargassum patens*. The leaflets, on the petioles of which the receptacles are borne, are narrowly linear, almost filiform, tapering gradually upward. They have no rib but have conspicuous cryptostomata along both edges.

Vesicles are always solitary at the base of the lateral branches, and not seldom the lowermost division of a receptacular ramulet is modified into a vesicle. They are ovate, apiculated while young, crowned with a long simple or furcated leaflet when fully grown, spotted with cryptostomata, and provided with a flattened stalk sometimes twice as long as the vesicle.

Receptacles are subcylindrical, granulose, each with a short cylindrical stem below. They are paniculately disposed on the lateral branches.

Relation to other species. The primary shoot and its manner of development suggest the subgenus *Schizophycus* J. Ag.; and the species evidently stands near the preceding species. The fertile ramules of both the present species and *Sargassum patens* are very much alike but the latter species has more receptacles to a ramulet; while the former has, as far as I have been able to ascertain, less than four of them. The two species, however, may be readily distinguished by their leaves.

Locality. Tosa Prov. (!).

Sargassum kashiwajimanum YENDO.

Plate VII. Fig. 4.

Diagnosis. Caule....., ramis complanatis ramulos a margine pinnatim emittentibus; ramulis teretibus pinnatis; foliis fulcrantibus brevissime stipitatis, palmatim pinnato-dichotomiis, laciniis linearibus, subdentatis, costatis; vesiculis maximis, in petiolo ipsas æquale, sphericis, foliis pinnatis vel simplicibus coronatis; receptaculis.....

Description of the species. The lower portions of the frond are not known. The stem is compressed with rounded edges, alternately pinnately ramose. The leaves on the principal branches grow patently from the edges of the complanated stem, with a very short petiole: they are decomponently pinnately or subdichotomously divided with the segments linear and the margins shallowly and irregularly dentated. An immersed rib traverses the whole length of the leaf running into the segments almost to the tip of each.

Vesicles are spherical, with complanated stipe nearly as long as the diameter, coronated with one or two or often three pinnately divided leaflets. They are axillary and solitary. A lateral branch starts from the axil formed by a vesicle and the principal stem.

Receptacles unknown.

Relation to other species. The specimen is fragmentary and the appearance of the entire plant is not known. But the characters shewn in the specimen at hand are quite unique and not referable to any described species. Unfortunately the specimen is sterile so that the exact systematic position can not be ascertained. The plant, however, should probably be grouped under *Schizophycus* J. Ag. and placed near *Sargassum patens*. From the latter it may be easily distinguished by the forms of the vesicles and the leaves.

Locality. Kashiwa-jima, Tosa Prov. (T. MAKINO) (!).

ARTHROPHYCUS J. Ag.

Sargassum kushimotoense YENDO.

Plate XVI. Fig. 20.

Prelim. List of Fue. Jap. p. 157.

Diagnosis. Radice scutellata, caule compresso, lævi, distiche pinnato; foliis verticalibus papyraceis in specimini exsiccatō glaucis, lanceolatis, breve stipitatis, immerse costatis, argute crispato-dentatis, irregulariter utrin-

que glandulosis; vesiculis in petiolo complanato elliptico-sphaericis, folio majore longe stipitato coronatis; receptaculis.....

Description of the species. In the preliminary list of *Fucaceae* of Japan, l. c., I mentioned the present species established from a fragmentary sterile specimen that I collected at Kushimoto, Kii Prov. Among the specimens preserved in the herbarium of the Sapporo Agricultural College, I also found a complete though sterile specimen of the same species, collected at Shibushi, Hiuga Prov. I do not hesitate to mention them under the new specific name on account of the unique characters revealed in the specimens.

The root is scutellate with a primary stem on it. The stems of the principal branches are smooth, subcompressed with rounded edges, from which the lateral branches are sent off distichously and alternately. The leaves on the principal branches are thin and papyraceous, turning a dirty whitish colour on drying due to a powder-like substance on the surface of the lamina. They are simple, linear-spathulate, narrowed above, measuring 5–10 cm. in length and 1.5–2 cm. in width at the broadest part. The petiole is complanated and short, and expands abruptly into the lamina. An immersed rib runs from the petiole quite to the apex of the leaf. Minute, dark cryptostomata are found on both sides of the rib, disposed with no apparent regularity. They are invisible except by translucent light, owing to the grayish hue of the leaves. The margin is coarsely dentated with sharp and spinulose teeth.

Vesicles are ovate or spherical with a long complanated stalk below and a large crown leaflet above. The latter is often as large as an ordinary leaf which it resembles, except that the basal portion gradually attenuates into a long compressed stalk. In the Kii specimen we have a bifurcated leaflet upon a vesicle, as shown in Pl. XVI. fig. 20. But this may be an abnormal case.

Systematic position of the species. Our specimens unfortunately lack the reproductive organ, and the exact relationship between the present species and the others is therefore uncertain. But the vesicles, in this species, are evidently transformed from the basal portions of simple leaves; and the branches do not result from the elongation of leaf-segments. This suggests to us to group the species under either *Bactrophyucus* or *Arthrophyucus*. It probably belongs to the latter subgenus standing near *Sargassum grande* or *Sargassum undulatum*. From these species ours may be easily distinguished by the peculiar corona and the smooth compressed stem. The present disposition is, however, a provisional one until we have a full knowledge of the reproductive organ.

Localities: Kushimoto, Kii Prov. (!); Shibushi, Hiuga Prov. (H. S. A.).

BACTROPHYCUS J. Ag.

Sargassum Horneri Ag.

Plate X.

Spec. p. 38.—*Id.*: System. p. 307.—J. Ag.: Spec. Alg. I. p. 290.—*Id.*: Spec. Sarg. Austr. p. 57.—*Id.*: Anal. Alg. Cont. III. p. 50 (*nomen*).—HARLOT: Alg. de Yokosk. p. 218.—DE TONI: Syll. Alg. III. p. 20.—*Id.*: Phyc. Jap. Nov. p. 43.—O. KUNTZE: Revis. von Sarg. p. 218 (*excl. syn.*) Pl. I. fig. 26.—*Id.*: Revis. Gen. Plant. III. 2. p. 429.—OKAM.: Enumer. Alg. of Jap. p. 144.

=*Fucus Horneri* TURN.: Hist. Fuc. Vol. I. p. 34. Tab. 17.

=*Spongocarpus Horneri* Kütz.: Ueber d. Eigent. s. 54.—*Id.*: Tab. Phyc. X. Taf. 89.—*Id.*: Phyc. Gen. p. 365.—SURING.: Alg. Jap. p. 26.—MARTENS: Preus. Exped. Tange. p. 116.

=*Sargassum spathulatum* J. Ag.: Spec. Sarg. Austr. p. 58. *adnot.*—*Id.*: Anal. Alg. Cont. III. p. 50.

=*Sargassum Horneri* var. *spathulatum* OKAM.: Enumer. Alg. of Jap. p. 144.

=*Sargassum Fengeri* J. Ag.: Spec. Sarg. Austr. p. 58.—*Id.*: Anal. Alg. Cont. III. p. 50 (*nomen*).—DE TONI: Syll. Alg. III. p. 21.—

Id.: Phyc. Jap. Nov. p. 43. (*excl. syn.*).—OKAM.: Enumer. Alg. of Jap. p. 144.

= *Sargassum polyodontum* J. Ag.: Anal. Alg. Cont. III. p. 51.—OKAM.: Enumer. Alg. of Jap. p. 145.

Description of the species. The frond is 2–5 feet in height, frequently attaining 16 feet in total length. The root is scutellate, irregularly lobed on the margin. From the top of the root rises a single erect stem which, in full grown forms, sends upwards lateral branches. The stem of a young frond of about half a foot in height is subcylindrical with small, sharp, spinous processes over the surface. In more fully grown individuals these spinous processes usually disappear at the basal region and the stem becomes 4–5 sided with the scars of the basal leaves spirally disposed (Pl. X. fig. 2, 3). The lower portions, however, of the stem as well as the branches retain the processes for a considerable time. In the middle and upper portions the stems are cylindrical, smooth and cartilaginous, usually with shallow longitudinal furrows running downward from the insertion points of the leaves. They are loosely twisted. The interfolial distance varies according to the habit of the plants, ranging from a few centimeters to 20 cm.

The basal leaves of young sterile plants are characteristic (Pl. X. fig. 1). They are linear-spathulate, alternately pinnately sected, the sinu being round and deep quite up to the midrib in the basal part of a leaf, but gradually becoming shallower and narrower towards the apex. The apex of a leaf is obtuse, or often roundish-truncate: segments truncate, directed slightly upward, and dentated at the apices. The size of segments in a leaf gently diminishes downwards until finally they are reduced to small but sharp spinous processes on the filiform petiole. The midrib is slightly elevated but sharply defined, and vanishes near the apex. On the upper surface of the rib there are frequently several spinous processes

in a row; but they are usually confined to the lower half of the leaf.

The leaves on the lower portions of the sterile lateral branches are similar to those above described in every respect, but usually much smaller. On the terminal portions of a frond they are much narrower and extremely delicate and membranaceous (Pl. X. fig. 7): often deeply alternately pinnatisected with the sinu deep and the segments ascending, sometimes shallowly dentated or even undulated; and sometimes with the apices of the leaves acuminate or spathulate. These variations are often met with in one and the same individual.

Vesicles are cylindrical, 10–14 mm. in length and 2–2.5 mm. in diameter. The apex of a vesicle ends abruptly in a simple, serrated crown leaflet with a long petiole, and the base in a short stalk. Many vesicles are usually found disposed in a raceme or cyme on the lower portion of a ramule.

Receptacles are cylindrical and terminal on a ramulet. The male and female receptacles are found on different individuals and differ in their external shape as has been described by KÜTZING¹⁾ though somewhat inadequately. The male receptacles are long and homogeneously cylindrical, mucronate above, and ending abruptly in a short stipe below (Pl. X. fig. 6). The female ones are much thicker and shorter, more or less attenuated upwards, and equally mucronate at the top (Pl. X. fig. 5). The conceptacles of both sexes begin to ripen first at the upper portion of a receptacle and then gradually lower down. Those that are discharging their contents are much swollen resulting in a much larger diameter in that part of the receptacle. KÜTZING's figures²⁾ illustrate the stage

1) Phyc. Gen. p. 365.

2) Tab. Phyc. Bd. X. Taf. 89. fig. c.

just referred to. The author¹⁾, undoubtedly through some misunderstanding, remarks that the spores are contained in the swollen upper half and the antheridia in the lower. Finally the whole of the receptacle becomes much swollen, and, at the same-time, extremely gelatinous and easily corruptible.

Remark on the synonymy. The vesicles and the basal leaves are characteristic of the present species. The young and sterile forms which are destitute of even a vesicle can be determined without the least doubt by the unrivalled character of the basal leaves; in a fragmentary specimen a vesicle enables us to surely tell the species. A study of a large stock of specimens from various parts of our coast convinces me of the unreliability of all other characters.

J. AGARDH²⁾ found in collections from Korea, Saghalin and Japan, some fragmentary specimens which had some characters varying from the ordinary form of *Sargassum Horneri*. They were more robust in texture, different in shape of leaves, and were more densely ramiferous. He was, however, in some doubt as to its specific value and noted it provisionally under the name *Sargassum spathulatum*. In his later work³⁾ he claimed a specific position for it. The essential character separating it from *Sargassum Horneri* was the obtuse apex of the leaves.

We have specimens from Sado Prov., Otaru Harbour, and Rikuchu Prov., which accord with the description of *Sargassum spathulatum* with remarkable accuracy. The main stem is always more robust, and the branches and branchlets, usually comparatively short, start out approximately: the leaves are spathulate,

1) Tab. Phyc. Bd. X. p. 31.

2) Spec. Surg. Austr. p. 58.

3) Anal. Alg. Cont. III. p. 50.

shallowly cleft with ribs evanescent in the upper portions. Some of the forms exhibit more divergent characters in the vesicles, being often subfusiform and not homogeneously cylindrical. There are, however, numerous forms which stand between these and the typical forms of *Sargassum Horneri*. The spatulate leaves are never constant in these specimens but may frequently be found on the typical ones. The branches are approximate or non-approximate, and the texture varies from robust to soft, according to the condition of the place where the plant grows. In general, in those which grow in the warmer and more sheltered seas the stems are slender, the interfolial distances longer, and the leaves broader and more deeply cleft.

In Spec. Sarg. Austr. p. 58, J. AGARDH described another species, viz. *Sargassum Fengeri*. Judging from the description I am not able to find any legitimate ground for separating it from *Sargassum Horneri*.

In Anal. Alg. Cont. III. p. 50, AGARDH described still another species from a lower portion of a sterile specimen, which had been collected by KJELLMAN in Japan. The author remarked that the species, i. e. *Sargassum polyodontum*, might be distinguished from *Sargassum Horneri* by its having a furrowed cylindrical stem instead of a triquetrous one. But as I have above stated, the cylindrical but furrowed stem is an important character of *Sargassum Horneri*, especially when yet young. The angulate stem is to be found at the lower portion of the older fronds, and is a result of the falling off of the basal leaves. I can not find any reason for mentioning *Sargassum polyodontum* as a distinct species or even as a variety.

It must be admitted that J. AGARDH's three species have been described from fragmentary or sterile specimens, which as

the author confesses, had none of their parts in a complete state. *Sargassum spathulatum* was first noted from an upper portion of a frond. He afterward found a lower portion of a frond that he believed to belong to the same species, which, in my judgement, was a local form of *Sargassum Horneri* apparently different from the sterile but normal specimen he ever possessed. The confusion has probably arisen from his ignorance of the complete form of the present species.

f. furcatodentatum O'KUNTZE. Plate X. Fig. 8.

Revisio von Sarg. p. 224. Pl. II. fig. 25.

Remark on the forma. I have mentioned above that when found in a warmer and more sheltered sea the plants assume a changed appearance. The essential and only difference between such plants and the typical form lies in the basal leaves of the young stems as well as in those of the sterile branches. They are much smaller in size and membranaceous in texture; deeply, alternately pinnately sected clear to the midrib throughout their whole length; the pinnæ, except those of the lowermost leaves, are narrowly linear, once or twice dichotomously or digitately divided, with each apex pointed and curved inward, the spinous processes along the upper surface of the rib being very conspicuous and almost always present. These characters are also manifested in some degree in the fulcrant leaves and the crown leaflets. The vesicles are usually proportionally small. This form, although it gradually approaches the ordinary forms through several intermediate stages, is by no means negligible. It is worth mentioning in a formal rank. Forma *furcatodentatum* O'KUNTZE, l. c., suggests the present form, and the photographic print accompanying the original paper illustrates an upper portion of it.

A specimen sent from the province of Satsuma has every part much elongated and delicate. The stem is almost filamentous, the vesicles elongated, crowned with a narrow undulated leaflet, and the receptacles unusually pronounced. Undoubtedly an extremity of the present forma.

Localities: Goto, Hizen Prov. (KJELLMAN, J. AGARDH); Korea (OKAMURA); Iwami Prov. (!); Izumo Prov. (!); Tango Prov. (!); Noto Prov. (!); Ugo Prov. (!); Fukuyama (H.S.A.), Hakodate (!), Esashi (H.S.A.), Usujiri (H.H.F.), Oshima Prov.; Otaru, Shiribeshi Prov. (H.S.A.); Ishikari Prov. (H.S.A.); Saghalin (FENGER, J. AGARDH); Mouth of Amur (FENGER, J. AGARDH); Shoya, Hidaka Prov. (H.S.A.); Rikuchū Prov. (!); Rikuzen Prov. (!); Shimōsa Prov. (!); Boshū Prov. (!); Sagami Prov. (!); Izu Prov. (!); Shima Prov. (!); Kii Prov. (!); Bungo Prov. (!); "Everywhere along the Pacific and Japan Sea side" (OKAMURA).

f. furcatodentatum: Mikawa Prov. (!); Kii Prov. (H. SC. COLL.); Iyo Prov. (H. YAMAMOTO) (!); Chikuzen Prov. (M. YANO) (!); Hizen Prov. (K. OSHIMA) (!).

Sargassum filicinum HARV.

Plate XI. Fig. 8.

Charact. of New Alg. p. 327.—J. AG.: Spec. Sarg. Austr. p. 58.—*Id.*: Anal. Alg. III. p. 50.—DE TONI: Syll. Alg. III. p. 21.—*Id.*: Phyc. Jap. Nov. p. 44.

Remark on the affinity. I have identified a few specimens, which, though fragmentary, exactly accord with the diagnosis and the photograph of the original specimen of the above named species. The plant has a strong resemblance to *Sargassum Horneri* as well as to *Sargassum kiushianum*. But the spherical vesicles of the present species readily separate it from the former and the

cylindrical, fusiform receptacles from the latter. It has also some apparent similarity to a certain form of *Sargassum micracanthum*, from which, however, it may be distinguished by the thin papyraceous texture of the leaves and the great elongation of the lateral branches, and by the truncated or bidentated segments of the pinnated leaves; and more easily, when fertile, by the shape of the receptacles. It is an unmistakable species but seems to be comparatively rare.

Localities: East coast of Japan (WRIGHT, HARVEY); Misaki(!).

Sargassum serratifolium AG.

Plate XI. Fig. 1-7.

- System. p. 299.—J. AG.: Spec. Alg. I. p. 291.—*Id.*: Spec. Sarg. Austr. p. 59.—*Id.*: Anal. Alg. Cont. III. p. 53.—DE TONI: Syll. Alg. III. p. 22.—*Id.*: Phyc. Jap. Nov. p. 44.—OKAM.: Enumer. Alg. of Jap. p. 148.
 = *Fucus serratifolius* AG.: Dec. No. 31.
 = *Fucus longifolius* var. *tenuifolia* TURN.: Hist. Fuc. Vol. II. Tab. 88.
 = *Halochloa longifolia* Kütz.: Tab. Phyc. X. Taf. 100.—*Id.*: Phyc. Gen. p. 367.
 = *Halochloa serratifolia* Kütz.: Tab. Phyc. X. Taf. 99.—*Id.*: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 56.
 = *Halochloa serratifolium* β *longifolia* KÜTZ.: Spec. p. 633.
 = *Fucus longifolius* TURN.: Hist. Fuc. Vol. II. p. 88. Tab. 104.
 = *Sargassum corynecarpum* HARV. (nec J. AG.): Charact. of New Alg. p. 328.—DE TONI: Syll. Alg. III. p. 25.—*Id.*: Phyc. Jap. Nov. p. 45.—OKAM.: Enumer. Alg. of Jap. p. 151.

Description of the species. At an early stage of development, the root is disc-shaped with a primary shoot upon it. The stem of the shoot usually ramifies at or near the very base. The stem of the primary shoot as well as the branches develop further, rapidly increasing in thickness and elongating by apical growth. The root eventually becomes a stout conical elevation often exceeding 4 cm. in diameter at the base. In a well

developed plant, as a consequence, the primary stem generally becomes confluent with the upper portion of the root, with the basal branches apparently starting multicipitally from the surface of the conical elevation. It is these basal branches which appear as the principal members of a frond. When old, their lower portions are cylindrical but irregularly verrucose from the scars left by the dropped basal leaves, and are mostly trunk-like. These stout stems, when only a few centimeters in length, ramify profusely.

The stem of a branch which is sent forth from the basal stem, is compressedly ancipitous with a longitudinal costal elevation on one surface, and provided with several spinous processes along the ancipitated margins.

While the plants are yet very young, measuring not more than 2 feet in height, the basal leaves are usually still to be found. In such specimens the leaves are strongly retrofractive, linear-spathulate, and irregularly dentated with a midrib running from the base nearly to the apex. The base of such a leaf is cuneate, round or often cordate, and is continuous to a short complanated petiole. The margins of the complanated stipule frequently expand into thin membranaceous wing-like appendages confluent above with the ancipitous margins of the stem. The substance of the leaves is mostly thick and coraceous without cryptostomata, but often very thin and membranaceous with inconspicuous cryptostomata or else entirely destitute of them. The leaves in the upper portion of a frond are linear-spathulate, duplicato-serrated, with the segments pointing obliquely upwards.

In these young forms vesicles are found solitary on the upper surface of the flat petioles. They are large and spherical, often measuring 1 cm. in diameter, coronated with a lanceolate or spathulate leaflet at the top, and with a stalk usually shorter

than the diameter. From the middle portion of the stalk a young lateral branch is given off. In some cases the base of the crown leaflet passes downwards along the longitudinal lines with small wings here and there.

The young plants of the above described forms attain their maximum size in April, and seem to develop no further during the summer. During that season the larger number of the basal leaves drop off, leaving the petioles together with the short lateral ramulets upon them. In the autumn of the same year these short ramulets begin to develop further. They continue to grow until the next spring, ramifying decompositely and alternately pinnately, attaining frequently several feet in length.

The stems of the ramulets, as well as of the ultimate portions of the principal branches, are tereto-triquetrous, and much more slender than the middle and upper portions of the stems of the latter. They are more or less twisted.

The duplicato-serrated leaves, characteristic of the present species, are found in large numbers in those plants which are collected late in winter or early in spring. These leaves mostly appear as the fulcrant leaves of the lateral branches. The leaves in the last mentioned parts, which support the minor ramulets, are much narrower and longer, attenuated in both directions, and mostly shallowly alternately pinnately dentated, with elevated midrib running nearly the entire length of the lamina. The leaves on the ultimate portions of the ramules as well as on the minor ramulets gradually become narrower, with obscure serrature and midrib.

The vesicles on these plants are elliptical, much smaller than those found in the young forms, measuring 6-8 mm. in length and 4-5 mm. in diameter. Some are coronated with a

narrowly linear, costated and serrated leaflet, while others are simply mucronated at the apex.

Receptacles are complanated, clavated or spathulated, often attenuated above, ending at the base in a short slender stalk. They are disposed in a panicle or raceme on the final ramulets of the upper branches. Receptacles of both sexes have a similar external appearance.

Remark on the synonymy. The present species is prone to a considerable variation in its vegetative organs, according to the condition of the environment and the season. The characteristic duplicato-serrated leaves are often obliterated even in the spring forms. In younger individuals, as above described, they are often entirely wanting. Hence the morphological value of the leaves in specific determination is sometimes very slight. The matured plants without the characteristic fulcrant leaves are, indeed, often liable to be confounded with *Sargassum tortile*. The distinction between these two species will be discussed in the next chapter.

On consulting the original diagnosis of *Sargassum corynecarpum* HARV., I was led to strongly suspect that it had been based on a specimen of *Sargassum serratifolium* which had lost its fulcrant leaves by age. The photograph of the original specimen of the former species showed that HARVEY's plant was undoubtedly an old specimen of the present species, with some basal leaves still undetached but having lost the fulcrant leaves on all branches. J. AGARDH¹⁾ referred a plant to *Sargassum corynecarpum* HARV., but his plant belongs to a quite different species, as may be easily seen by comparing the descrip-

1) Anal. Alg. Cont. III. p. 57.

tion with HARVEY's diagnosis. Cf. also the remarks under the heading of *Sargassum Kjellmanianum* in the present work.

Sargassum serratifolium AG. has been doubtfully referred to *Sargassum tortile* by J. AGARDH. He also added that *Halochloa macrantha* Kütz. might be referred to the latter species. These three plants, in my judgment, can scarcely be separated unless one is supplied with a complete set of specimens of each.

I shall not say anything about the opinion of O'KUNTZE¹⁾ who declares that the present plant belongs to *Sargassum vulgare* and *Sargassum medium*.

Localities : Loochoo (OKAMURA); Shimabara, Hizen Prov. (MARTENS); Tsushima (H. S. A.)(!); Izumo Prov. (!); Tango Prov. (!); Sado Prov. (!); Rikuzen Prov. (!); Shimōsa Prov. (!); Boshū Prov. (!); Sagami Prov. (!); Shimoda, Izu Prov. (WRIGHT, HARVEY under *Sargassum corynecarpum*); Shima Prov. (!); Awa Prov. (!); Tosa Prov. (H. YAMAMOTO) (!); Bungo Prov. (!).

Sargassum tortile AG.

Plate XII. Fig. 1-8.

Dec. No. 2.—*Id.*: System. p. 299.—*Id.*: Spec. p. 15.—J. AG.: Spec. Alg. I. p. 291.—*Id.*: Spec. Sarg. Austr. p. 60.—*Id.*: Anal. Alg. Cont. III. p. 53 (*excl. syn.*).—DE TONI: Phyc. Jap. Nov. p. 44.—*Id.*: Syll. Alg. III. p. 23 (*excl. syn.*).—OKAM.: Enumer. Alg. of Jap. p. 147.

?=*Fucus longifolius* var. *angustifolius* TURN.: Hist. Fuc. Vol. II. p. 88. Tab. 104. fig. b.

=*Halochloa tortilis* Kütz.: Tab. Phyc. X. Taf. 99.—*Id.*: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 56.

=*Fucus scoparius* TURN.: Hist. Fuc. Vol. II. p. 156. Tab. 132.

=*Sargassum scoparium* AG.: Spec. p. 26.—J. AG.: Spec. Alg. I. p. 292.—*Id.*: Spec. Sarg. Austr. p. 60.—DE TONI: Syll. Alg. III. p. 23.

1) Revisio von Sarg. p. 216.

- =*Halochloa scoparia* Kütz.: Spec. p. 634.—*Id.*: Tab. Phyc. X. Taf. 95.
- =*Halochloa pachycarpa* Kütz.: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 55.—*Id.*: Spec. p. 34.—*Id.*: Tab. Phyc. X. Taf. 96.
- =*Halochloa siliquastra* Kütz.: Spec. p. 634.—*Id.*: Tab. Phyc. X. Taf. 97. fig. 1.
- =*Fucus siliquastrus* TURN.: Hist. Fuc. Vol. III. p. 26. Tab. 82.
- ?= *Sargassum siliquastrum* J. AG.: Spec. Alg. I. p. 292.—*Id.*: Spec. Sarg. Austr. p. 60.
- ?= *Cystoseira siliquastra* AG.: System. p. 288. pp.
- ?= *Sargassum siliquastrum?* var. *pyriferum* HARV.: Charact. of New Alg. p. 328.
- ?= *Carpacanthus trichophyllus* Kütz.: Spec. p. 622.—*Id.*: Tab. Phyc. XI. Taf. 37. fig. 2.—*Id.*: Phyc. Gen. p. 368.—*Id.*: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 57.
- ?= *Halochloa tenuis* Kütz.: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 57.—*Id.*: Phyc. Gen. p. 367.—*Id.*: Spec. p. 623.—ОКАМ.: Enumer. Alg. of Jap. p. 160.—J. AG.: Spec. I. p. 292.

Description of the species. In a well grown individual the stem is a stout cylindrical trunk arising from the top of a hemispherical or compressed conical root, which measures 2–3 cm. in diameter. The average length of a frond measures 3.5–4 feet but frequently as much as 8 feet. The stem, in most cases, sends out numerous branches at a distance of a few centimeters from the base. These branches divide repeatedly, resulting finally in a number of subordinate branches.

The stems of the youngest principal branches are cylindrical and smooth on the lower portions but above become gradually compressed. Coarse spinous processes are usually present on the margins of the complanated portions of the stems. The leaves on these stems are thick, coriaceous, dark-brown, oblongo-ovate or spatulate, slightly elevated at the costal region, and irregularly and roughly serrated on the margins. As in the preceding species, the subordinate branch grows out from the upper surface

of the petiole of the basal leaf, which sooner or later drops off as the branches develop further.

The lateral branches on the principal members play the important part of a frond. When just starting, their stems are compressed and ancipitous sending out strongly retrofractive leaves alternately from the surfaces of the stems. As the interfolial distances measure but a few centimeters, such stems bend in a zigzag manner with a leaf at each angulate point. The leaves on the basal regions of these sterile branchlets are spatulate or lanceolate, frosted in some individuals with cryptostomata which may however be wanting in others: they are thick and coreaceous in texture, dark brown in colour, mostly irregularly serrated, and with an immersed midrib. The upper leaves, however, are narrow, linear-lanceolate, brownish in colour, immersedly costated, with or without cryptostomata, and sharply and subregularly alternately pinnately dentated. The laciniae are obliquely triangular, directed upwards, and ending in a sharp point. Every one of these leaves on the lateral branches may, after further development, become a fulcrant leaf supporting a lateral branch upon the petiole.

The leaves on the lesser indefinite branches are very narrow, sharply serrated as in the upper fulcrant leaves. They become narrower by degrees, as we trace them upwards, till the lamina is finally reduced to a wing-like appendage along the rib, or often becomes quite filiform. The laciniae of the serrature become likewise narrower and claw-like, obliquely reflexed above, and regularly alternately pinnately disposed. Very often the indefinite branches just above the basal leaves are stunted with approximate retrofractive leaves, which are usually setaceous with a few prickly-like dentations.

The stems of the minor branches, as above remarked, are

ancipitous, often with a few spines along the margins. In the upper portions of the more developed branches, however, they become triquetrous and are often very strongly twisted. The stems of the fertile branchlets are slender, filiform and triquetrous or terete.

Vesicles are mostly found solitary near the base of the terminal ramulets. They are pear-shaped, often subspherical, mucronated at the apex or with a setaceous crown leaflet, and with a short, slender, cylindrical stalk. In a specimen kindly given me by Mr. R. TSUGE, who collected it in the province of Wakasa, the setaceous crown leaflets are so very pronounced as to give a piluliferous appearance to the upper portions of the frond. Frequently the apex is crowned with an alternately pinnately serrated, filiform leaflet. The size of a vesicle varies according to its position in the frond, but the largest ones measured 1 cm. in length and 0.8–0.6 cm. in diameter.

Vesicles are in most cases not met with in the young branches but are found abundantly on the upper portions of the full grown but sterile fronds: in April, when the plants become fertile, the fronds are very poor in vesicles as they are mostly given off in this season.

Receptacles are linear-spathulate, clavate or elongato-elliptical, compressed with round margins, more or less attenuated below ending in a short cylindrical stalk. They are disposed in a raceme on a final ramulet with a filiform, simple setaceous bractlet at the base of each. The bractlets easily drop off and often no trace of them is to be found on the frond, except their insignificant scars. The result shows an apparent similarity to the receptacular ramulets of the members of the section *Siliquosae* under the *Eusargassum* J. Ag.

f. macrocarpa YENDO. Plate XII. Fig. 8.

Prelim. List of Jap. Fuc. p. 156.

=*Sargassum macrocarpum* Ag.: System. p. 307.—*Id.*: Spec. p. 36.—
J. Ag.: Spec. Alg. I. p. 293.—*Id.*: Spec. Sarg. Austr. p. 60.—
Id.: Anal. Alg. Cont. III. p. 53.—OKAM.: Enumer. Alg. of
Jap. p. 146.—DE TONI: Syll. Alg. III. p. 24 *p.p.*—*Id.*: Phyc.
Jap. Nov. p. 44.

=*Halochloa polyacantha* Kütz.: Tab. Phyc. X. Taf. 98.—*Id.*: Ueber
d. Eigent. (Bot. Zeitg. 1843.) s. 56.

=*Halochloa macracantha* Kütz.: Tab. Phyc. X. Taf. 97. fig. 2.

Remark on the forma. I identify one plant as *Sargassum macrocarpum* Ag. As the original diagnosis is so very simple that it may be applied to other allied species, my identification is mostly based on the descriptions given by J. AGARDH. If the determination by the present writer has been correctly done, the plant is by no means a valid species but may be connected with the typical form of the present species by various gradations. Still it often exhibits some remarkable characters and is worthy of mention in a formal rank.

The essential characters of the frond are similar to the type. The total length of a well grown plant often measures 7–8 feet with the lateral branches as long as 1–1.5 feet. The vesicles at the basal portions of the lower branches are remarkably large attaining sometimes 2cm. in length, with a short sub-ancipitous stalk, crowned with a narrow, dentated, ribbed, and glandulated leaf. Those on the terminal branchlets are nearly equal to those of the type. The leaves sometimes become as long as 15–18cm. and are generally very stiff and coriaceous, with the ribs distinctly elevated almost to the tips. The margin is coarsely but deeply dentated with the sinu round and the laciniae deltoid and curved upwards. The cryptostomata are conspicuous in some individuals but entirely wanting in others. The spinous processes

on the margin of the lower ancipitous stems are prominent and abundant but, gradually diminish in number on the upper stems.

Remark on the synonymy. The present species is the most perplexing one in the study of the *Sargassum* of Japan. Extraordinary confusions have occurred in the specific conception of the European herbarists, particularly on account of the divergent opinions of J. AGARDH and KÜTZING.

J. AGARDH discounted the specific value of *Halochloa scoparia* Kütz. and referred it once to *Sargassum macrocarpum* J. Ag.¹⁾ and afterward to *Sargassum tortile* Ag.²⁾ He³⁾ declared that KÜTZING's plant was different from *Fucus scoparius* TURN. which he mentions as a distinct species: and he referred *Halochloa pachycarpa* Kütz., though sometimes⁴⁾ with doubt, to TURNER's species. Judging from the figures of *Halochloa scoparia* Kütz. in Tab. Phyc., l. c., I have no doubt that it is identical with *Sargassum tortile* Ag., and the descriptions and figures of *Sargassum scoparium* Ag. or *Fucus scoparius* TURN. prove no reasonable mark to distinguish the latter from KÜTZING's. In a similar manner, J. AGARDH⁵⁾ combined *Halochloa siliquastra* Kütz. with *Sargassum tortile* Ag., while he⁶⁾ mentioned *Fucus siliquastrus* TURN. as an independent species under the name of *Sargassum siliquastrum*. But the distinction between KÜTZING's and TURNER's plants, as made out from references, is entirely worthless in practice.

DE TONI⁷⁾ combined *Sargassum siliquastrum?* var. *pyriferum* HARV. with *Sargassum macrocarpum* J. Ag. The reason for his

1) Spec. Sarg. Austr. p. 60.

2) Anal. Alg. Cont. III. p. 53.

3) Spec. Sarg. Austr. p. 60.

4) Anal. Alg. Cont. III. p. 53.

5) Spec. Sarg. Austr. p. 60.

6) Anal. Alg. Cont. III. p. 55.

7) Syll. Alg. III. p. 24.

having done so is not clear to me. Judging from the original diagnosis, HARVEY's plant seems to be a form referable either to *Sargassum serratifolium* or to *Sarg. tortile*, with the fulcrant leaves off. Prof. WRIGHT wrote me when I asked for a photograph of HARVEY's original specimen, that he could not find any bearing that name in the herbarium of Trinity College.

Carpacanthus trichophyllum Kütz. seems extremely doubtful to me. DE TOXI¹⁾ has placed it under the questionable species. It has exactly the same characters as *Sargassum tortile* except that the receptacles are "ad angulos spinoso dentata." So far as my researches on the Japanese forms of *Sargassum* extend, I can not believe such a species occurs on our coast. The plant which KÜTZING had illustrated was probably a specimen of the present species with shrunken receptacles apparently angulate.

Fucus heterophyllus is assigned to Japan by TURNER²⁾ J. AGARDH^{3) 4)} seems to doubt its occurrence in Japan, which is reasonable, and mentions it under *Sargassum siliquastrum*. The figures delineated by TURNER are incomplete; they are referable to *Sargassum serratifolium* or rather to *Sarg. tortile*. He remarks, however, of the receptacles: "some solitary, others growing two or three together,"—which is not a character of the present species.

J. AGARDH⁵⁾ referred *Fucus longifolius* & *angustifolius* TURN. to the present species. But TURNER's original description and illustration may at once be applied to both *Sargassum serratifolium* and this species. It may not be possible to solve the problem before seeing TURNER's original specimen.

1) Syll. Alg. III. p. 118.

2) Hist. Fuc. Vol. II. p. 62.

3) Spec. Alg. I. p. 293.

4) Spec. Sarg. Austr. p. 60.

5) Spec. Alg. I. p. 291.

Halochloa pachycarpa Kütz. has been established undoubtedly on a basal portion of a local form of *Sargassum tortile*. The plant is characterized by the enormous dilatation at the residual portions of the fallen basal leaves. I illustrate a plant which agrees very well with KÜTZING's figure, from a sheltered cove at Hamajima in the Province of Shima. The upper portions of this aberrant form, however, satisfactorily prove it to belong to the present species. (Pl. XI. fig. 4).

Halochloa polyacantha I refer to *f. macrocarpa*, though I do so with hesitation. The much divided laciniae of the pinnatisected leaves, as delineated by KÜTZING, l. c., were not verified in our collections.

Localities: Nagasaki (TILESIIUS, AGARDH), (HORNER, TURNER), Hizen Prov. (!); Chikuzen Prov. (M. YANO) (!); Tsushima Prov. (H. S. A.); Fusan, Korea (H. SC. COLL.); Nagato Prov. (H. SC. COLL.); Izumo Prov. (!); Tango Prov. (!); Hakodate (H. H. F.), Esashi (H. H. F.), Oshima Prov. (!); Ugo Prov. (!); Shimōsa Prov. (!); Sagami Prov. (!); Shima Prov. (!); Kii Prov. (H. SC. COLL.); Awa Prov. (H. S. A.); Sanuki Prov. (!); Aki Prov. (!); Satsuma Prov. (H. S. A.).

f. macrocarpa: Sagami Prov. (H. S. A.); Kii Prov. (H. S. A.); Tsushima Prov. (H. S. A.); Tango Prov. (!); Noto Prov. (!); Sado Prov. (!).

Sargassum fulvellum Ag.

Plate XIII. Fig. 18–20.

Spec. p. 34.—*Id.*: System. p. 306.—J. AG.: Spec. Alg. I. p. 293 (*excl. syn.*).—*Id.*: Spec. Sarg. Austr. p. 61.—*Id.*: Anal. Alg. Cont. III. p. 55.—DE TONI: Syll. Alg. III. p. 25.

= *Fucus fulvellus* TURN.: Hist. Fuc. Vol. I. p. 148. Tab. 66.

= *Spongocarpus fulvellus* Kütz.: Spec. p. 633.—*Id.*: Tab. Phyc. X. Taf. 90.

Description of the species. Fronds of a matured plant measure 2-2.5 feet in total length. The root is complanated, disc-shaped and has a subcylindrical stem on its top. The scars of the fallen basal leaves, as in many other members of the *Bactrophycus*, give to the lower portion of the stem a knotty appearance. Several fastigiate branches are sent forth in all directions from the stem at a few centimeters above the root. The stems of the branches are triquetrous, slightly twisted with a few dentations on the ridges, but gradually become terete and smooth upwards.

The leaves on the sterile branches as well as on the lower portions of the fronds are retrofractive, elongato-elliptical with round apex and short complanated and often winged petiole. In the fresh specimens they are dark brown in colour and thick and cartilaginous in texture. Small but well defined cryptostomata are discernible in translucent light. The margin is generally entire but in some leaves on young sterile branches it is often coarsely serrated. As a rule, these serrated leaves are variable in their shape ranging from ovate to lanceolate according to individuals and the locality of the plant. An elevated midrib runs through the meridional line and disappears before reaching the apex.

The leaves on the fertile branches are highly variable in their shape according to their position in the frond. On the lower portions they are mostly lanceolate or spatulate, very often obliquely cuneate, with comparatively short stipe and sparingly serrated or entire margin. Those on the upper portions are narrow, cuneate or spatulate, tapering towards the base into a long stipe; mostly entire at the margin but frequently sparingly dentated. The midrib becomes gradually obsolete as the

leaves ascend, the number of the cryptostomata at the same time diminishing.

The leaves on the minor branchlets are narrow and filiform, mostly with neither rib nor cryptostoma.

Vesicles are pyriform, with very short stipe at the base and quite round at the apex. In some cases a few mucronated vesicles are found among the muticous ones; and often an individual with all the vesicles mucronated is met with. A specimen from the Province of Izumo belonged to the latter category but had exactly the same characters as the others in the remaining points. As a rule two or three vesicles are found in a dwarfed raceme at the base of the ramulet. No cryptostomata on the vesicles.

Receptacles are elongato-conical, 3–5 mm. in length, obtuse at the apices and with a very short pedicel at the base. They are found, in matured plants, in dense racemose branchlets. Excepting the few terminal ones, each of them is accompanied by a small filiform, subulate and spotted bractlet.

Remark on the identification. The descriptions and illustrations of *Sargassum fulvellum* AG. are largely applicable to our plant, except in a few points. The pallidity of the frond, which characterized the species, has not been proved in our specimens. The material on which the original description was based had probably been bleached as J. AGARDH¹⁾ has already noted. In defining the species C. AGARDH²⁾ and TURNER³⁾ used the expression “foliis.....enervibus.” Our plant, however, has the leaves mostly evanescently costated except those on the terminal parts

1) Spec. Sarg. Austr. p. 61.

2) System. p. 306.

3) TURN.: Hist. Fuc. Vol. I. p. 147.

of the subordinate branchlets. It must be remembered that the next species has leaves absolutely destitute of midrib, and that its fronds are very liable to lose colour when cast ashore. The figure, indeed, of *Fucus fulvellus* illustrated by TURNER is applicable to both this and the following species. The greater part of the description by TURNER also applies to both plants. But he notes that the plant does not adhere in the least to the paper. *Sargassum enerve* is remarkable for adhering closely to the paper on drying, while the plant here treated never does so.

J. AGARDH¹⁾ remarks that the vesicles of the present species are mucronated; and DE TOXI²⁾ notes that the mucronation measures 2.2mm. In our plant, however, as has been shown above, most of the vesicles are entire at the top, and mucronated ones are rather uncommon. They say also, “folia vix uncialia, paullo ultra 3mm.” This remark applies to the upper portions only of the frond of this plant.

It is to be remembered that the present writer has never seen an authentic specimen of either TURNER’S or J. AGARDH’S. There is, therefore, no little danger in disputing the former descriptions; but it may be said with safety that in Japan we find no other plants than the one now described and the next one which presents a close agreement with the descriptions of *Sargassum fulvellum* AG.

Localities: Nagasaki (MARTENS), Iizen Prov. (!); Iwami Prov. (!); Izumo Prov. (!); Tango Prov. (!); Sado Prov. (!).

1) Spec. Alg. I. p. 293-294.

2) Syll. Alg. III. p. 25.

Sargassum enerve Ag.

Plate XIII. Fig. 1-6.

Spec. p. 17.—*Id.*: System. p. 279.—J. AG.: Spec. Alg. I. p. 294 (*excl. syn.*).—*Id.*: Spec. Sarg. Austr. p. 61.—*Id.*: Anal. Alg. III. p. 55.—KÜTZ.: Tab. Phyc. XI. Tab. 13.—HARIOT: Alg. de Yokosk. p. 218.—MARTENS: Preus. Exped. Tange. p. 116.—DE TONI: Syll. Alg. III. p. 25.—*Id.*: Phyc. Jap. Nov. p. 45.—OKAM.: Enumer. Alg. of Jap. p. 149.
 = *Sargassum fulvellum* OKAM.: Enumer. of Alg. of Jap. p. 149.
 = *Spongocarpus enervis* KÜTZ.: Ueber d. Eigent. (Bot. Zeitg. 1843.) s. 55.—*Id.*: Tab. Phyc. X. Taf. 89. II.—*Id.*: Phyc. Gen. p. 365.—O'KUNTZE: Revisio von Sarg. p. 220.

Description of the species. The root is a depressed cone with a simple erect stem on its top. In a shoot just starting the leaves are sent off spirally upwards from very near the base. The leaves are strongly retrofractive, linear-spathulate or cuneate, irregularly dentated, attenuated below into a more or less elongated petiole. From the petiole a costal elevation passes into the lamina but disappears within a very short distance. The substance of the leaves is thick but soft, dark brown in colour, and without cryptostoma. Short lateral branches, not exceeding an inch in length, with several large vesicles at each base, are seen on the upper portions of these young plants.

The plants with the above features generally attain full development early in the spring, reaching 2-3 feet in height. Then the basal leaves begin to drop off. Late in the autumn, the majority of the basal leaves disappear, and the axial stem elongates considerably, often attaining 15 feet in total length, the lateral branches developing proportionally at the same time. In the vicinity of the Biological Laboratory at Misaki, the receptacles are discharging their contents early in January. The stems of the matured plants are in the middle and the upper

portions triquetrous or quadrangulate with prominent ridges, and unexclusively twisted. The stems of the lateral branchlets are cylindrical but in the lower portions slightly angulate. The leaves on the lower portions of the lateral branches are spatulate, sub-obtuse at the apex, attenuated below into a petiole; coarsely serrated on the margin, ribless, with many minute dark spots. Those on the upper portions, especially on the fertile branchlets, are much smaller, linear-clavate or often obliquely cuneate and slightly dentated on the margin, and are extremely soft in texture. It is owing to the latter character that the present is the principal species of *Sargassum* used as food by the fishermen in certain parts of Japan.

The vesicles at the base of a lateral branch in young and sterile shoots are ellipsoidal or obovate, measuring 12–13 mm. in length and 8–9 mm. in diameter. They are usually slightly compressed with an inconspicuous longitudinal ridge over the apex. The apices of the vesicles are generally round, but often mucronate or even crowned with a small leaflet. The vesicles on the matured fronds are obovate, sometimes pyriform, with a very short stipe, usually round at the apex, but occasionally fusiform and apiculated. They rarely exceed 5 mm. in length.

Receptacles are elongato-conical, shortly pedicelled, each borne on a small, subulate and complanated bractlet, except the terminal one. They are disposed in a raceme on the terminal branchlets.

Remark on the synonymy. KÜTZING¹⁾ declared that *Sargassum enerve* Ag. and *Spongocarpus enervis* Kütz. are different plants. But they belong to one and the same species, as J. AGARDH²⁾ had

1) Phyc. Gen. p. 365.

2) Spec. Sarg. Austr. p. 61.

suspected. The character of the vesicles which the former writer pointed out in distinguishing both are demonstratively unreliable.

J. AGARDH¹⁾ and DE TONI²⁾ remarked that the present species has a close affinity to *Sargassum fulvellum* AG. and the former writer once united *Sponcarpus enervis* Kütz. with it. Both are, indeed, nearly related, but may be easily distinguished by various points as already mentioned under the preceding species.

J. AGARDH³⁾ relates that the plant which he received from MARTENS with the name of *Fucus pallidus* is equal to *Sargassum enerve* AG., while the plant described and figured by TURNER in Hist. Fuc. Vol. I. t. 67 bearing the former name is quite different from the latter. The figures of *Fucus pallidus* illustrated by TURNER, i. e., and of *Halochloa pallida* by KÜTZING in Tab. Phyc. X. 94. II. do not coincide with the present species in several important characters. These figures, incomplete as they are, are rather referable to *Sargassum piluliferum* AG. or a variety of it.

O'KUNTZE⁴⁾ remarks that *Sargassum enerve* is a hybrid between *Sargassum vulgare* and *Sargassum Horneri*. On what ground his opinion is based is beyond our imagination.

Localities: Chikuzen Prov. (M. YANO)(!); Korea (TILESUS); Hagi, Iwami Prov. (J. NIKAI); Izumo Prov. (!); Tango Prov. (!); Noto Prov. (!); Rikuzen Prov. (!) Shimōsa Prov. (!); Boshū Prov. (!); Sagami Prov. (!); Izu Prov. (!); Shima Prov. (!); Kii Prov. (!); Awa Prov. (!); Sanuki Prov. (!); Bungo Prov. (!); "Everywhere along the coast of the Pacific Ocean and the Japan Sea" (OKAMURA).

1) Spec. Sarg. Austr. p. 61;—Spec. Alg. I. p. 294.

2) Phyc. Jap. Nov. p. 45.

3) Spec. Alg. I. p. 294.

4) Revisio von Sarg. p. 222.

Sargassum hemiphyllum Ag.

Plate XIII. Fig. 7-17.

- Spec. p. 39.—*Id.*: System. p. 307.—J. AG.: Spec. I. p. 331.—*Id.*: Spec. Sarg. Austr. p. 61.—*Id.*: Anal. Alg. Cont. III. p. 56.—DE TONI: Syll. Alg. III. p. 26.—*Id.*: Phyc. Jap. Nov. p. 45.—DICKIE: Alg. Jap. in Journ. Linn. Soc., Bot. Vol. XV. p. 45.—OKAM.: Enumer. Alg. of Jap. p. 150.
 = *Fucus hemiphyllus* TURN.: Hist. Fuc. Vol. III. p. 86, Tab. 169.
 = *Spongocarpus hemiphyllus* KÜTZ.: Spec. p. 633.—*Id.*: Tab. Phyc. X. Taf. 90.
 = *Sargassum hemiphylloides* KÜTZ.: Spec. p. 608.—*Id.*: Tab. Phyc. XI. Taf. 7.
 = *Sargassum hemiphyllum* var. *sinense* J. AG.: Spec. Sarg. Austr. p. 61.—DE TONI: Syll. Alg. III. p. 26.
 = *Sargassum hemiphyllum* var. *micromerum* J. AG.: Spec. Sarg. Austr. p. 62.—DE TONI: Syll. Alg. III. p. 27.
 = *Sargassum micromerum* J. AG.: Anal. Alg. Cont. III. p. 57.
 = *Sargassum chinense* J. AG.: Anal. Alg. Cont. III. p. 56.

Description of the species. The roots are ramose, irregularly dividing as they extend, with the ramuli spreading radially and horizontally. Some of the ramuli more elongate than the rest, having the appearance of a stolon. I am not certain whether a new shoot may start out from the stolon-like ramuli or not. But none of the numerous specimens in our hands proves a vegetative multiplication by budding from the ramuli.

The stem of a young frond usually branches at a point a few millimeters above the root. The branches become nearly as long as the primary frond and have similar characters in all respects. The stems of the branches hardly exceed 1.5 mm. in diameter. They are spirally beset with the characteristic asymmetrical leaves, the interfolial distances ranging from 3 to 8 mm. or more.

The leaves on the lower portions of the stems are cuneate, obovate or oblongo-elliptical, more or less attenuated below and

minutely serrated at the upper margin, or often entire. They are usually destitute of cryptostomata, and are frequently symmetrical. Those on the upper portions of the principal stems, as well as those on the lateral branches, are without exception asymmetrical and situated perpendicularly. They are obliquely cuneate in general outline, attenuated below and ending in a filiform petiole. The upper margin is entire and recurved upward, the lower is minutely or coarsely dentated, not infrequently subentire. The total length of the leaves varies to a considerable degree even in the same individual, ranging from $\frac{1}{2}$ cm. to 3 or more cm. When the plant has attained maturity the fulcrant leaves on the principal members have mostly dropped off, and the lateral branches play the important part of the frond. The leaves on the terminal ramulets are usually narrowly cuneate, entire, or shallowly bi-trifid at the apices.

The lateral branches are axillary. As the fulcrant leaves are perpendicularly situated, the branches grow apparently from the base of the smooth upper margin. This character in a fair degree distinguishes the plant, together with a few others, from the rest of the *Bactrophycus*.

The stems of the lateral branches are more slender than those of the principal members. The leaves on them are proportionately smaller, and very approximately disposed. These leaves have in most cases the lesser ramulets arising from their axils which sooner or later become provided with the receptacles. The ramulets usually measure 2–4 cm. in length, but frequently do not exceed one centimeter.

Vesicles are found on the lower portions of the ramulets. They are liable to a considerable variation in shape according to the individual and to their position in the frond. As a rule

those on the lower portions of a frond are obovate or pyriform, often with round apices, while on the upper they are elliptical or oblongo-obovate and mucronated at the apices. Frequently, they appear like an inflated leaf with a wing-like appendage at the margin. These variations occur sometimes in the same, sometimes in different individuals.

Receptacles are cylindrical, about 1mm. in diameter, 3-6mm. in length, more or less attenuated above, and abruptly ending below in a short stipe. They are racemosely disposed at the upper portion of the terminal branchlet. When the latter has been much depressed they appear in a small cluster with a few vesicles at the base. A small, subulate bractlet accompanies each receptacle except the terminal one.

Remark on the synonymy. J. AGARDH distinguished two varieties of *Sargassum hemiphyllum* AG., calling them *var. chinense* and *var. micromerum* in Spec. Sarg. Austr. l. c. In his later work, Anal. Alg., l. c., he raised them both to specific rank. A close examination, however, of rich collections of the plant from various localities made at various seasons proves that the characters pointed out by J. AGARDH to distinguish the three species are not diagnostic, and that it would be better to unite them into one species. The size of the leaves is, first of all, wholly unreliable for specific or varietal distinction. It varies according to the parts of the frond and also according to individuals. In an aberrant form collected by myself at Cape Shiomizaki, in the Province of Kii, I found the leaves on the lateral branches nearly as large as the fulcrant leaves on the main stems. The roundness or sharpness of the apices of the leaves is a much more unfixed character. Frequently plants are found with leaves decidedly entire at the margin and round at the apices.

Sargassum hemiphylloides Kütz. was suspected by J. AGARDH to be nearly related to *Sargassum chinense*. He, however, left it in doubt, as KÜTZING's figure had a regular dentation on the outer margins of the leaves. This character as well as the round-headed vesicles shown in the figure presents no objection to a union of KÜTZING's plant with the present species.

Localities: Nagasaki (!); Hagi, Iwami Prov. (H. SC. COLL.); Hakodate (H. SC. COLL.); Boshū Prov. (!); Sagami Prov. (!); Izu Prov. (!); Suruga Prov. (!); Shima Prov. (!); Awa Prov. (!); Tosa Prov. (!); Ise Prov. (K. TANI) (!); Osumi Prov. (H.S.A.); Hiuga Prov. (H.S.A.).

Sargassum Kjellmanianum YENDO.

Plate XV. Fig. 1-5.

Prelim. List of Jap. Fuc. p. 158.

?= *Sargassum corynecarpum* J. AG.: (nec HARV.) Anal. Alg. Cont. III. p. 57.

Diagnosis. Radice scutellata subconica; caule tereto sursum longitudine striato, subtortili, quoquoversum ramoso; ramis lateralibus filiformibus ramossissimis; foliis fulcrantibus oblongo-obovatis apice obtusis, stipitis brevissimis, subdentatis, ecostatis, minute glandulosis, superioribus ramulorumque minoribus, subspathulatis vel lanceolatis rarius oblique cuneatis, parce dentatis, medio singula serie cryptostomatibus glandulosis; vesiculis in petiolo ipsis brevioribus subsphaericis vel pyriformibus, mucronatis, parce glandulosis; receptaculis cylindraceis, brevissime stipitatis, in ramulo ultimo racemosis.

Description of the species. A well grown plant measures 75-120 cm. in height, and is attached to the substratum by a small, depressed, conical root. The primary stem is subterete and hardly exceeds 1 inch in length, sending out several branches fasciculately from the top. At an early stage of development these branches are bud-like with numerous, thick, scale-like leaves

disposed spirally around the abbreviated stem. The diameter of the stem measures ca. 1.5mm. and seems to gain a little even in a fully grown form. As the branches elongate upwards the scale-like leaves gradually increase in size. The leaves on the portion several centimeters above the root are generally oblongo-obovate, 1.5–2.5cm. long and 3–4mm. wide, with obtuse apex, sparingly serrated, ribless and with or without spots. The substance of the leaves is thin but coreaceous. They almost all fall off before the frond attains its maturity.

The lateral branches at the lower portions of the principal members are short, hardly one inch long; but they become gradually longer on the upper portions and eventually ramify decomponently. Stems of the branches are cylindrical, filiform and smooth. The leaves on these branches and branchlets are very small, about 5mm. in length, and 1.5mm. in width, with a few dentations on the margins; subspathulate or lanceolate in shape. Often some of the leaves are bifid cuneate and sometimes apparently hemiphyllous. Most of them have a few cryptostomata in a series along the median line, as in the leaves of *Sargassum confusum*.

Vesicles are subspherical or pyriform, less than 3mm. in length, with a stalk about half as long as the vesicles, sparingly dotted with minute cryptostomata. The apices of the vesicles are generally mucronate but some of the upper young ones are fusiform. Two or three vesicles are generally found in the lower portion of an ultimate ramulet. Very frequently the bractlet below a receptacle is swollen at the apex into a small roundish vesicle; or occasionally a small vesicle with a long stalk is given off from the lateral side of a receptacle.

Receptacles are cylindrical, attenuated upwards, with a short stalk below, growing solitary at the base of a subulate, filiform

or narrowly lanceolate bractlet. They are disposed in a raceme on the terminal portion of the ultimate ramulet.

***f. muticus* form. nov.**

Diagnosis. Foliis inferioribus majoribus, lanceolatis, ecostatis, minute dentatis, superioribus ramulorumque cuneatis sæpe obliquis bi-tridentatis, medio irregulari unica serie cryptostomatibus glandulosis; vesiculis obovatis muticis rarius mucronatis.

Remark on the forma. What has been said above on the type may in large part be applied to the present forma. The essential points separating it from the type are the leaves of young sterile branches and the shape of the vesicles. The leaves on the basal portion of a young frond are lanceolate, ribless, and minutely serrated or coarsely dentated. They often attain 2 cm. in length and 5 mm. in width. The leaves on the upper ramules are bi-tridentated, cuneated and frequently subhemiphyllous, with minute cryptostomata irregularly disposed along the median line. Vesicles are mostly obovate, muticous, but in rare cases some in an individual are aristated or mucronated, and frequently spotted with a few cryptostomata.

This forma is limited, as far as our collection extends, to the warmer parts of the Pacific side of the Main Island. The typical form seems to exist in the colder seas only.

Remark on the affinity to other species. The plant has apparently a close resemblance to *Sargassum hemiphyllum* in its general aspect and texture, but it may be readily distinguished from the latter species by its simple scutate root and by the greater elongation of the ultimate ramulets.

J. AGARDH describes a plant from Hakodate, collected by KJELLMAN, under the name of *Sargassum corynecarpum* HARV. I am in considerable doubt about his plant. He says¹⁾

1) Anal. Alg., Cont. III. p. 57.

that it bears a close resemblance to *Sargassum hemiphyllum*. *Sargassum corynecarpum*, as already stated (p. 84), was established by HARVEY on a withered specimen of *Sargassum serratifolium*. Although J. AGARDH had never seen an authentic specimen of HARVEY's species, it is rather surprising that he should refer a plant which had some likeness to *Sargassum hemiphyllum* to the diagnosis of such a widely differing species as *Sargassum corynecarpum* HARV. Judging from the description given in Anal. Alg. Cont. III. l. c., his plant seems to come near the present species, though it is said to have immersedly costated leaves and apparently fibrous roots. In our plant the root is small and scutate. But when the basal stem is greatly diminished in length, the adventitious buds from the lower portions of the main branches give the appearance of a fibrous root. The basal leaves in our plant, again, are frequently evanescently elevated on the meridional line, but the upper ones are decidedly ribless. It is with some hesitation that I refer the present species to the plant that J. AGARDH mentioned under the name of *Sargassum corynecarpum*; it may, however, be safely stated that his plant is remote from HARVEY's, but is closely related to the species here described, if not identical with it.

Sargassum Thunbergii f. *latifolia* is closely allied to the present species. The young shoots of both, indeed, are almost indistinguishable the one from the other. When fully grown, however, both exhibit several characters which enable us to separate them quite easily. In the present species the leaves on the upper ramules are cuneate, bifid cuneate or often linear-lanceolate, but rarely filiform; the vesicles have longer and more delicate stipes; and the vesiculiferous ramulets are not abbreviated as in *Sargassum Thunbergii*. The young and sterile specimens

of the latter species show an external resemblance to *Rhodomela Larix* or *Chordaria abietina*, while those of the present species exhibit no such appearance. In the aged fronds of *Sargassum Thunbergii* the primary stem is quite hard to recognize, while in the present species the short subterete stem remains unchanged.

Localities: Fukushima (H. H. F.), Hakodate (H. S. A.), Yesashi (H. S. A.), Toppu (H. S. A.), in Oshima Prov.; Takashima (H. S. A.), Yoichi (H. H. F.), Shiribeshi Prov.; Yangeshiri Isl., Teshio Prov. (H. H. F.); Rishiri Isl. (H. S. A.), Notoro (H. S. A.), Soya (H. H. F.), Kitami Prov.; Akkeshi, Kushiro Prov. (H. S. A.); Nishiura, Kumasiri Isl. (H. H. F.); Shana, Etorofu Isl. (H. H. F.); Rikuzen Prov. (!).

f. muticus: Rikuzen Prov. (R. TSUGE) (!); Boshū Prov. (!); Sagami Prov. (!); Shima Prov. (!); Kii Prov. (!); Chikuzen Prov. (!).

Sargassum confusum AG.

Plate XIV. Fig. 1-12.

System. p. 301.—J. AG.: Spec. I. p. 294.—*Id.*: Spec. Sarg. Austr. p. 127.—*Id.*: Anal. Alg. Cont. III. p. 60.—KÜTZ.: Spec. p. 610.—DE TONI: Syll. Alg. III. p. 115.—*Id.*: Phyc. Jap. Nov. p. 46.—OKAM.: Enumer. Alg. of Jap. 158.

= *Sargassum acinaria* MARTENS: Preus. Exped. Tange. p. 128.

= *Sargassum acinaria* KÜTZ.: Tab. Phyc. XI. Taf. 17. fig. II.

= *Fucus heterophyllus* AG.: Dec. No. 52.

? = *Sargassum fuliginosum* KÜTZ.: Spec. Alg. p. 612.—*Id.*: Tab. Phyc.

XI. Taf. 19.—J. AG.: Anal. Alg. Cont. III. p. 60.—DE TONI:

Syll. Alg. III. p. 117.—OKAM.: Enumer. Alg. of Jap. p. 158.

—? MARTENS: Preus. Exped. Tange. p. 116.

? = *Fucus pallidus* TURN.: Hist. Fuc. Vol. I. p. 150. Tab. 67.

Description of the species. The root is a complanated disc with a single stem rising from its top. The primary stem seems never to exceed a few inches in height even in the mature plant. The important function of the frond is played by the copious

branches which are sent off more or less alternate-pinnately from the principal stem. In a well grown individual the total length of the frond measures 2-5 feet. While the primary and also the principal branches are yet very young they are cylindrical but densely beset with small, sharp, spinous processes. The leaves on them are linear-spathulate or obovate, often attaining 7 cm. in length. They are thick and coriaceous in substance, evanescently costated, with sparingly dentated or entire margin, and frosted with many cryptostomata.

As the plant further develops the basal leaves on the lower portion of the primary stem fall off, leaving prominent angulate elevations on its surface. The principal branches elongate upward, the leaves gradually decreasing in size, and send out eventually a lateral branch from the axil of each new leaf. The fulcrant leaves seem to drop off soon after the lateral branches have appeared, but the large basal leaves often remain solitarily for a considerable time. The lateral branches and the upper portions of the principal branches are mostly smooth and cylindrical but frequently are subangulate.

The leaves on the lateral branches vary considerably in size and shape. It is owing to this character and to the length of the ultimate branchlets that the fronds of the present species are frequently quite dissimilar. The average leaves on a sterile branch are linear-lanceolate, 3-4 cm. long and 3-4 mm. or less wide, acute at the apices and tapering downwards into filiform petioles; the margin is entire, the substance thin and papyraceous, and several prominent cryptostomata are found in a series along the median of each lamina. We occasionally meet with a specimen in which the cryptostomata are hardly detectable. The leaves on the fertile ramulets are mostly filiform or narrowly linear-clavate.

Vesicles are generally found on the basal portions of the ultimate branchlets. Those fully grown are spherical or sub-spherical, round at the apices, with a stalk at the base nearly as long as the diameter of the vesicle. The young ones are often obovate and apiculated. They are provided with few but well defined cryptostomata.

Receptacles are cylindrical, more or less narrowed above, each, excepting the apical ones, borne on the foot of a filiform, subulate bractlet. They are racemosely disposed at the terminal portion of the ultimate branchlets.

f. valida YENDO. Plate XIV. Fig. 8-12.

Prelim. List of Fuc. Jap. p. 160.

?=*Sargassum validum* J. AG.: Anal. Alg. Cont. III. p. 59.

=*Sargassum expansum* J. AG.: l. c. p. 60.

Remark on the forma. J. AGARDH in his paper Anal. Alg. Cont. III. described two new species calling them *Sargassum validum* and *S. expansum*. These two species are distinguished essentially from each other as well as from *Sargassum confusum* by the characters of the rib and the arrangements of the cryptostomata on the upper leaves, and the dentations of the basal leaves. After careful study of the material in our hands I have decided to unite the two species into one and mention it as a forma of the present species. It must be remembered, however, that I have not seen any of the authentic specimens of AGARDH's plants and the present disposition is therefore a provisional one. But as far as I could judge from our specimens, provided that I have referred them to J. AGARDH's species correctly, the specific characters pointed out by that author are by no means constant, and often are reversed. The cryptostomata on the leaves of the lateral branches are, as above noted, occasionally wanting. The

patentness of the lateral branches, the number of the spinous processes on the stems, etc., are also quite unreliable characters.

The present forma may be separated from the type to some extent by having the basal leaves mostly lanceolate, with the rib extending nearly to the apex of each, and irregularly serrated at the margin. In some of the specimens from the vicinity of the Otaru Bay, the serrature on the leaves is remarkably regular; yet plenty of specimens from other localities serve to link them with those having entire spatulate leaves. Linear-spatulate, ribbed leaves are not uncommon in the upper portions of the present forma. When the basal leaves have fallen off this and the typical forma are often hardly distinguishable.

Remark on the synonymy. The original diagnosis of *Sargassum validum* is at once applicable to both *Sargassum confusum* and *Sargassum fulvellum* in the specific conception taken in the present paper. J. AGARDH described *Sargassum validum* from the material collected by KJELLMAN at Hakodate. *Sargassum fulvellum* seems to be limited to the warmer parts of Japan, and its occurrence in the vicinity of Hakodate seems to me very doubtful; while *Sargassum confusum* is commonly found along the coast of Hokkaido (Yesso). Hence I choose to refer the questionable species, *Sargassum validum*, rather to the northern species.

Fucus pallidus TURN. is a problematic species. J. AGARDH¹⁾ once referred it, though with doubt, to *Sargassum enerve*, but he neglected it in his later works. Referring to TURNER's Hist. Fuc. I. c., I believe that it may be identical with the present species. The figure of *Halochloa pallida* in Tab. Phyc. X. Taf.

1) Spec. Alg. I. p. 294.

94, is rather referable to *Sargassum piluliferum*. If *Fucus pallidus* be nothing but the present species, the name *Sargassum pallidum* must stand instead of *Sargassum confusum* according to the rule of priority.

J. AGARDH¹⁾ mentions a plant which he thought probably a young form of *Sargassum validum*. I can not but suspect, judging from his note, that his plant may have been a basal portion of *Sargassum patens* var. *Schizophylla*. None of the young and sterile specimens of the present species in our collection verifies his remark.

Sargassum fuliginosum KÜTZ. seems to me an extremely doubtful form. It is assigned by KÜTZING to the coast of Kamtschatka. We have reason to believe that, in Japan, *Sargassum* has its northern limit at the southern end of the Kurile Islands. J. AGARDH refers, though with doubt, a plant from Jeto (Jeso?) to this species. It is not clear whether the plants of both writers belong to exactly the same species or not; but, as far as the references extend, KÜTZING's plant seems to come near the present species if not to be a form of it.

J. AGARDH considered as doubtful *Sargassum acinaria* KÜTZ. reported from Korea. The lower portions of the plant are not figured, and the leaves at the base of the lateral branches have the ribs almost quite to the tip. The general appearance of the plant, judging from the illustrations in Tab. Phyc. l. c., suggests a part of the present species.

Remark on the affinity to other species. J. AGARDH added a new section *Angulata* to the subgenus *Eusargassum*, and *Sargassum validum*, *S. expansum*, etc., were included in it. He

1) Anal. Alg. Cont. III. p. 59.

notes that the receptacles of these species have an arrangement similar to that of the members of the *Bactrophyceus* while the characters of the vesicles have a greater resemblance to those of the *Eusargassum*. The present writer can not hold with the opinion that the roundness or apiculation of the vesicles in a frond is a sufficiently important point to serve for subgeneric distinction. As has been repeatedly stated in the preceding chapters, the vesicles are in some species generally muticous in the lower parts of the fronds, while in the upper and younger portions they are often apiculated or mucronated. In *Sargassum enerve* which is undoubtedly a member of the *Bactrophyceus*, some of the vesicles are round-headed in the young sterile fronds; and in *Sargassum fulvellum* some of the vesicles are muticous while others in the same individual are apiculated. In *Sargassum Kjellmanianum* we noticed that the southern and the northern forms differed essentially in the shape of the vesicles. In *Sargassum Ringgoldianum* which has been counted as a member of the *Bactrophyceus*, the vesicles are coronated with an enormously prolonged spathulate leaflet, while the receptacular ramulets claim a position for the species somewhere outside that subgenus.

Sargassum Miyabei has a close resemblance to the present species. They are so alike that in sterile specimens the species may not be discriminated with safety. When fertile, however, the former can be readily separated from the latter by the absence of the bractlets at the bases of the receptacles. Other points will be discussed later on.

Localities: Cape Nomo, Hizen Prov. (KJELLMAN, J. AGARDH); Fusan, Korea (N. YABE, HERB. SC. COLL.); Hagi, Iwami Prov. (J. NIKAI, HERB. SC. COLL.); Wakasa Prov. (R. TSUGE)(!); Noto Prov. (K. OKAMURA); Echigo Prov.(!); Shimofuro, Mutsu

Prov. (!); Hakodate (H.S.A.) (H.H.F.) (!), Fushikido (H.S.A.), Kudo (H.H.F.), Esashi (H.H.F.), (H.S.A.), Toppu (H.S.A.), Oshima Prov.; Bikuni (H.H.F.), Otaru (H.H.F.), Temiya (H.S.A.), Suku-zushi (H.S.A.), Takashima (H.S.A.), Shiribeshi Prov.; Chikubetsu (H.H.F.), Yangeshiri (H.H.F.), Mashike (H.H.F.), Teshio Prov.; Abashiri (H.H.F.), Shiretoko (H.H.F.), Kitami Prov.; Shibetoro (H.H.F.), (H.S.A.), Etorofu Isl.; Shiranuka, Mutsu Prov. (!); Ōshima, Rikuchū Prov. (!); ? Nagasaki (MARTENS).

f. validum: Korea (CROUAN, J. AGARDH, under *S. validum*); Iwami Prov. (!); Hakodate (!) (KJELLMAN, J. AGARDH under *S. validum*); Ishikari Prov. (H.S.A.); Rebun Isl., Kitami Prov. (H.S.A.).

Sargassum Miyabei sp. nov.

Plate XIV. Fig. 13-14.

Diagnosis. Caule communi breve mox fasciculate ramosa, ramis cylindraceis filiformibus, in inferiore parte simplicis, foliosissimis, in superiore ramulosis; foliis anguste linearibus, deorsum attenuatis, integerrimis, parce glandulosis; vesiculis in petiolo ipsas superante, ellipticis vel fusiformibus, mucronatis, glandulosis; receptaculis cylindraceis breve stipitatis, bracteolis in vesiculam transformatis, in ramulo racemosis.

Description of the species. In the specimens in our hands the root is incomplete and we are unable to determine its exact character. The primary stem seems not to exceed an inch or two in length, with several principal branches starting fasciculately near its apex, as in *Sargassum Thunbergii*. The stems of the principal branches are slightly angulate, measuring 1.5-2.0 mm. in diameter. A young branch is invariably covered densely with narrow lanceolate leaves, disposed approximately and spirally. When a frond has become old these rich leaves drop off, and the stems eventually become very rough with the

leaf-scars. Leaves are, as a rule, narrowly lanceolate, acuminate above, and gradually attenuated towards the base into a delicate filiform petiole. The margins are almost always entire but sometimes coarsely dentated in the upper portion of the leaf. A few obvious, elevated cryptostomata occur on the leaves.

Vesicles are elliptical, apiculated above, and acuminate below into a long filiform stipe. They are disposed racemosely on the lateral branches on which not a single leaf, except the fulcrant leaf, is usually to be found. And on the ultimate ramulets the fulcrant leaf itself is always transformed into a vesicle. Hence when a plant is sterile there is danger of its being mistaken for a *Cystophyllum*.

Receptacles are cylindrical, unarmed, tapering above, with a short filiform stipe; borne solitarily on each stipe of a vesicle or terminal on the ramulets.

Remark on the affinity. The plant has a close resemblance to *Sargassum confusum* on the one side, and to *Sargassum Thunbergii* on the other. One is liable to refer the young shoots, densely covered as they are with small leaves, to either of these two species, or to *Sargassum Kjellmanianum*. A fertile branch, however, readily distinguishes the present species from the others.

The disposition of the receptacles and vesicles of this species is somewhat aberrant among the *Bactrophytus*. It may be taken as an extreme form of the *Racemosa*, standing near *Sargassum nipponicum*, with the receptacular ramulets reduced to single receptacles only. But I am inclined to think it an ally of *Sargassum confusum*. The essential difference between them lies in the fact that in the former the bractlets on the ultimate fertile ramulets are invariably transformed into vesicles. Such a modi-

fication, however, though in a lesser degree than in this case, is very commonly met with in the fronds of *Sargassum*. The species next mentioned is an actual example.

Localities: Esashi and Hakodate, Oshima Prov. (H.H.F.); Zenibako, Shiribeshi Prov. (H.S.A.); Rishiri Isl. (H.H.F.); Cape Soya (H.H.F.), Kitami Prov.; Nikishoro and Chashitsu, Kunashiri Isl. (H.H.F.).

Sargassum Thunbergii O'KUNTZE.

Plate XV. Fig. 5.

Revisio Sarg. p. 215.—*Id.*: Revisio Gen. Plant. III. 2. p. 427.

=*Fucus Thunbergii* MERT.: in ROTH. Catalect. Bot. III. p. 104. Tab.

III. fig. a, c-e.—TURN.: Hist. Fuc. Vol. II. p. 158. Tab. 133.

=*Cystoseira Thunbergii* AG.: Spec. p. 81.

=*Rhodomela Thunbergii* AG.: System. p. 199.

=*Myagropsis Thunbergii* KÜTZ.: Spec. Alg. p. 635.—*Id.*: Tab. Phyc. X. Taf. 93. fig. II.

=*Cystophyllum Thunbergii* J. AG.: Spec. Alg. I. p. 233.—DE TONI:

Syll. Alg. III. p. 153.—*Id.*: Phyc. Jap. Nov. p. 47.—OKAM.:

Enumer. Alg. of Jap. p. 140.

=*Turbinaria (?) Thunbergii* YENDO: Prelim. List of Jap. Fuc. p. 153.

Remark on the species. The present species is one of the most common algæ found at the high tide mark along the coast of nearly the whole of Japan. The colour of the fronds is dark olive-brown, but it turns, except in the vesicles, an intense black on exposure to the air, as is usual with all brown algæ which occur between the tide marks. The external appearance of the plant is extremely variable according to its age as well as to the condition of the habitat. The essential characters which give the plants such a divergent appearance are the length of the lateral branches and the internodal distance.

In the embryonal stage of the plant, the principal branches,

not exceeding an inch in length, are provided, like the buds of the *Asparagus*, with spirally disposed, scale-like, imbricate leaves. Then they commence to send out a short lateral branch from each axil of the scale-like leaves. The whole aspect of a principal branch in this stage is simple and vermicular, apparently resembling *Rhodomela Larix*. When further grown with the lateral members eventually more distant and elongated, the frond becomes decompoundly and densely ramose. TURNER'S Hist. Fuc., l. c., illustrates these stages in a satisfactory manner, and the diagnosis hitherto given to the species very well applies to such forms. Some of the forms found in the northern parts as well as on the coast of the Japan Sea side have more or less distinctly marked characters to be distinguished from those above stated. Hence the following:—

f. typica, nov. nom.

=*Fucus Thunbergii* TURN. Hist. Fuc., l. c.

f. latifolia, form. nov.

Diagnosis. Ramis lateralibus brevioribus, foliis fulcrantibus lanceolatis, ramulorum subulato-lanceolatis, sæpe oblique cuneatis, parce glandulosis; vesiculis obovatis, mucronatis, sæpe muticis; receptaculis cylindraceis breve stipitatis.

f. nipponica, form. nov. Plate XV. Fig. 5.

Diagnosis. Ramis lateralibus longissimis densissime vesiculiferis; foliis fulcrantibus subulato-lanceolatis, angustissimis, ramulorum plerumque in vesiculas transformati; vesiculis minoribus, ellipsoideis, apiculatis; receptaculis cylindraceis, stipitatis, in ramulo abbreviato solitariis.

Description of the formæ. *Forma typica* flourishes in the warmer parts of the Pacific side of Japan from 30° to 40° N. latitude. It is characterized by having filiform leaves throughout the whole of the frond except at the base. The lateral branches are always

quite short, rarely attaining 3cm. in length, and are densely beset with abbreviated ramulets. Vesicles are oblongo-obovate, with a long stalk at the base and apiculated at the top. They are evidently inflations of the upper portions of the filiform leaves. Receptacles are cylindrical, more or less narrowed above, with a short stipe, and disposed in a racemose manner. Some specimens found in the vicinity of Nagasaki had the lateral branches as long as several centimeters and the receptacles measured 1 cm. in length with a diameter of a little over 0.5mm. The vesicles together with the receptacles are, as in the other formæ, generally limited to the abbreviated ramulets or to the terminal portions of the branches. The stems of the principal branches are ridged and measure 1.5–2 mm. in thickness in the middle portion.

Forma latifolia lives in the colder seas and is found on the coast of Hokkaido as far north as Etorofu Island. Its southern limit is near Kinkwasan Island, a little south of 40° N. latitude. The fulcrant leaves, i.e., the leaves on the principal branches, are lanceolate, and often as wide as 3 mm. Those on the lateral branches are complanated, subulato-lanceolate and usually have a few cryptostomata. On an average they measure ca. 0.5 mm. in width and 5 mm. in length. In the specimens from northern localities they apparently tend to have a greater width. In the specimens from the east coast of Hokkaido, these narrow lanceolate leaves are no longer found on the lower portions of the frond and in their place there are obliquely cuneate or spathulate leaves, 6–7 mm. long and 3–4 mm. wide. The assigning of *Sargassum hemiphyllum* to the northern part of Hokkaido may have been due to an erroneous identification of this forma. The vesicles begin to appear after the plant has grown more than a foot in height. At the beginning they are nothing but slight inflations

in the apical part of a more or less broadened leaf. When fully formed they become more spherical than those of *f. typica* and are frequently inermous. The receptacles are cylindrical, more or less narrowed above and have a short filiform stipe.

At an early stage of development, this forma is hardly separable from *f. typica*. But as soon as the fronds have reached half a foot in height, the characteristic broad fulcrant leaves serve unmistakably to distinguish it from the others. In a full grown individual the frond attains 3-4 feet in total height. The lateral members are much further apart than in *f. typica* and their average length is less than an inch. The stems of the principal branches are 2-3 mm. thick, and are five-ridged. A ridge is generated downwards from each insertion point of the leaves which are disposed spirally upwards in a screw-wise direction.

Forma nipponica also is not easily separable from *f. typica* while it is yet young. When it has attained to about a foot in total height, the lateral branches elongate to a considerable degree, often exceeding the principal branches in length. The ramulets on the lateral branches are quite stunted and approximate. The leaves on the ramulets are almost all transformed into small apiculated vesicles. The richness of the vesicles in the lateral branches is an important point in the practical distinction of this forma from *f. typica*. Receptacles are found at the terminal point of the stunted ramulet, and are usually solitary.

This forma is most abundant on the Japan Sea side from Nagasaki as far as Saghalin. On the coast of the Pacific side it seems to be confined to the vicinity of the eastern entrance of the Tsugaru Strait.

Remark on the systematic position. It can be easily demonstrated

from a fertile specimen that the receptacles or the receptacular ramulets are axillary. This character certainly excludes the plant from the genus *Cystophyllum* and necessitates its reference to *Sargassum*. Hence the name *Sargassum Thunbergii*, proposed by O'KUNTZE in the works referred to above, although his generic conception differs from ours, must be preferred according to the rule of priority. In *f. typica* and *f. latifolia*, the fulcrant leaves in the lower as well as in the middle portions of the fronds are filiform or lanceolate. In *f. nipponica*, they are almost always transformed into vesicles. Fig. 5 illustrates a portion of a fertile lateral branch of the latter form. In it one ramulet has an inflated fulcrant leaf and another a lanceolate one. This character, no doubt, suggests the close affinity of the present species to *Turbinaria(?) fusiformis*.

That the receptacles are axillary or apparently axillary is an important point in separating *Turbinaria* and *Sargassum* from the other genera of *Fucaceae*. I prefer to place the present plant and the following one under the genus *Sargassum*. In my former paper—the Preliminary List—I have referred it with some hesitation to the genus *Turbinaria* on the ground that it showed several points of morphological similarity to *Turbinaria(?) fusiformis*. The fulcrant leaves, however, of this and of the next species are in the majority of cases foliose and not vesiculiform, and this suggests the propriety of arranging the two species as is here done. Some of the specimens of this species, especially of *f. latifolia*, exhibit some resemblance to *Sargassum Kjellmanianum*. In some sterile specimens, indeed, it is often difficult to distinguish the two species except by close examination.

Localities: *f. typica*; Higo Prov. (!); Chikuzen Prov. (M. YANO) (!); Shirikishinai (H.H.F.), Fukuyama (H.H.F.), Esashi

(H.H.F.), Oshima Prov.; Raiden (H.H.F.), Bikuni (H.H.F.), Temiya (H.S.A.), Sukuzushi (H.S.A.), Shiribeshi Prov.; Moyoro (H.H.F.), Onnebetsu (H.H.F.), Kitami Prov.; Shitsukari, Hidaka Prov. (H.H.F.); Rikuchū Prov. (H.S.A.); Rikuzen Prov. (H.S.A.); Boshū Prov. (!); Sagami Prov. (!); Izu Prov. (!); Suruga Prov. (H.S.A.); Shima Prov. (!); Kii Prov. (H.SC.COLL.); Tosa Prov. (!); Bungo Prov. (H.S.A.); Osumi Prov. (H.S.A.).

f. latifolia; Hakodate (!); Shimofuro, Mutsu Prov. (!); Shari-utoro Cape, Kitami Prov. (H.H.F.); Nemuro (!); Shoya, Hidaka Prov. (H.S.A.); Rikuzen Prov. (!); Rikuchū Prov. (!).

f. nipponica; Hizen Prov. (!); Fusan, Korea (H. YABE, H.SC.COLL.); Tsushima Prov. (Y. YABE, H.SC.COLL.); Izumo Prov. (!); Tango Prov. (!); Wakasa Prov. (R. TSUGE) (!); Echigo Prov. (!); Todohokke (H.S.A.), Zenigamezawa (H.S.A.), Hakodate (!), Kamaya (H.S.A.), Oshima Prov.; Rishiri Isl. (!); Urakawa, Hidaka Prov. (H.H.F.); Tosa Prov. (!).

Sargassum Swartzianum nom. nov.

= *Fucus Swartzii* Ag.: in Act. Holm. 1815. p. 105. t. 4. fig. a-b.

= *Rhodomela Swartzii* Ag.: System. p. 198.

= *Cystoseira Swartzii* Ag.: Spec. p. 82.

= *Myagropsis Thunbergii* var. *Swartzii* Kütz.: Spec. p. 635.

= *Myagropsis Swartzii* Kütz.: Tab. Phyc. X. Taf. 93. fig. 1.

= *Fucus Thunbergii* var. *racemosus* ROTH.: Catalect. Bot. III. Tab. 3. fig. b.

= *Cystophyllum Swartzii* J. Ag.: Spec. Alg. I. p. 233.—DE TONI: Syll. Alg. III. p. 157.—Id.: Phyc. Jap. Nov. p. 47.—OKAM.: Enumer. Alg. of Jap. p. 140.

= *Turbinaria* (?) *Swartzii* YENDO: Prelim. List of Jap. Fuc. p. 153.

Remark on the species. This species has hitherto been distinguished from the preceding by the vesicles being evolved from the middle portions of the leaves. This, however, is never

accurate and often quite unreliable. KÜTZING¹⁾ illustrates some of the leaves as having two inflations successively or in a series. The greater number of the typical forms of the present species, when fully grown, have this sort of vesicles. I am tempted to believe that this character is rather important in the discrimination of the two species. Besides, this species may be easily distinguished from the preceding by its yellowish colour and soft texture. The fulcrant leaves are mostly as broad as, or broader than, those of *f. latifolia* and are spotted with a few well defined cryptostomata. In some specimens I found the basal leaves slightly dentated with the general outlines linear-lanceolate. It must be remembered, however, that given the young fronds alone, it is usually difficult to distinguish the present species from the preceding except with practice.

The occurrence of two inflations serially in a leaf is an uncommon character among the species of *Sargassum*. The same sort of arrangement of vesicles has been met with in several species of *Cystophyllum*. This fact made me hesitate to refer the present species to the genus *Sargassum*. But the receptacles are, as in the preceding species, evidently axillary, which, in the limitation of *Cystophyllum* by recent botanists, proves the impropriety of the generic position hitherto acknowledged.

Localities: “Pacific side, from Kiushū to the southern part of Hokkaido.” (OKAMURA); Takashima, Shiribeshi Prov. (H.S.A.); Sawara (H.H.F.), Osatsube (H.H.F.), Oshima Prov.; Shiretoko, Kitami Prov. (H.H.F.); Enoura (H.SC.COLL.), Izu Prov.(!); Shima Prov.(!).

1) Tab. Phyc. X. Taf. 93. fig. 1.

MICRACANTHÆ.

Receptaculis ovatis, complanatis, ancipitibus, apice vel margine minute dentatis, petiolatis, nunc in axilla ramulorum solitariis nunc in ramulo contracto aggregatis.

The following three species present a remarkable peculiarity in the receptacles. The fertile ramulets are always so abbreviated that they are not able to carry more than three receptacles on each. In extreme cases, only one receptacle, accompanied by a single leaf at its base, represents a fertile ramulet. The receptacles are ovate, ancipitous, excavated on one surface and longitudinally elevated on the other, and minutely spinosodentated on the margin or at the apex. The roots are scutate or tuberculate, and the stems mostly angulate; leaves simple, pinnatisected or entire, with or without cryptostomata; vesicles coronated with a simple leaflet, or often apiculated.

These species should undoubtedly be included under the subgenus *Bactrophycus* on account of the undivided receptacles and the other characters. But the dentation on the margin of the complanated receptacles claims for them a systematic position different from the other members. They might better be placed under an independent subgenus if preferred, but I choose to simply mention them in the new section above named under the subgenus *Bactrophycus*.

Sargassum kiushianum sp. nov.

Plate XV. Fig. 6-9.

Diagnosis. Caule....., ramis filiformibus, quadrangularibus, longitudine striatis, ramulis undique egredientibus; foliis linearibus, costatis, membranaceis, profunde alterne pinnatifidis, lacinii linearibus vel triangularibus sæpe apice bidentatis; vesiculis in petiolo filiformi ipsas subæquante sphericis, folio pinnatifido coronatis; receptaculis complanatis ovalibus dorso longitudine elevatis, margine minute dentatis, in axilla ramulorum solitariis.

Description of the species. The basal portion of the frond is unknown. The stem (possibly of the principal branch) is quadrangular, ca. 2mm. thick, with longitudinal furrows as in the case of *Sargassum Horneri*. It is loosely twisted with the lateral branches disposed spirally upwards. The leaves on the stem are thin and membranaceous, pinnatisected, with the general outline linear or linear-lanceolate. The lamina is almost reduced to an elevated, undulating midrib, which becomes a filiform petiole below. The laciniae are ascending, subulate, narrowly linear, acuminate or shallowly bi-tridentated at the apices. No cryptostomata are found in our specimen. The leaves on the lateral branches are essentially similar to those on the stem, but are smaller and narrower, with the laciniae obliquely triangular. The apices of the leaves on both parts are pointed or narrowly truncated.

Vesicles are solitarily disposed near the base of the lateral ramulets. Those found in the lower portions of the frond are spherical, but those in the upper, ovate or elliptical; they are coronated with a pinnatisected leaflet, or sometimes simply mucronated; stipes short and filiform.

Receptacles are complanated, obovate, ca. 5mm. in length, with a cylindrical stalk. They are longitudinally elevated on one surface and shallowly concave on the other, and minutely serrated on the margin.

Remark on the affinity. The present species is closely related to the next. It may, however, be easily distinguished by the membranaceous texture of the leaves, the extremely narrow laciniae, the solitary receptacles, etc. It has also a strong resemblance to *Sargassum filicinum* in the vegetative organs, so that the sterile specimens of both plants are almost indistinguishable from each other.

Locality. Chikuzen Prov. (M. YANO) (!).

Sargassum micracanthum (Kütz.)

Plate XV. Fig. 10-21.

Sargassum (*Halochloa*) *micracanthum* was first established by KÜTZING from a plant collected in Japan by TILESUS. J. AGARDH mentions the same species in Anal. Alg. Cont. III. p. 52, based on material collected in the same place by KJELLMAN. The specimens which reached both writers were unfortunately sterile and the reproductive organ was consequently unknown. There is no little risk in identifying a plant with the above named species as we have within our boundaries at least three distinct plants, all worthy of specific rank and to all which, when sterile, KÜTZING's specific definition of the above may be applied equally well: these are *Sargassum filicinum* HARV., *Sargassum kiuschianum*, and the plant under consideration. The present identification is hence a provisional one, done with the hope that my doubts will be cleared away by some one who has the chance of studying the authentic specimens.

Among the specimens in our hands, which accord with the descriptions by the two writers, there are two well defined varieties, if not species. KÜTZING's description is more applicable to the one, which I choose to call *var. typica*; the other, i.e., *var. stipulata*, has many characters coinciding with J. AGARDH's description.

var. typica YENDO: Prelim. List of Fuc. Jap. p. 158.

Plate XV. Fig. 10-17.

=*Halochloa micracantha* Kütz.: Ueber d. Eigent. (Bot. Zeitg. 1843) s. 56.—*Id.*: Spec. Alg. p. 633.—*Id.*: Phyc. Gen. p. 367.—*Id.*: Tab. Phyc. X. Taf. 98. fig. II.

Description of var. *typica*. Roots are complanated, disc-shaped, irregularly sinuated at the margin. From the upper surface of the disc there start usually several principal stems which ramify

at a short distance from the base. Not infrequently we meet with a form which has many unbranched stems starting multicapitally from a prostrate disc.

The stems of young shoots are cylindrical at the basalmost portion but soon become angulate above. In the middle portions of fronds they are, as a rule, triquetrous, more or less twisted, and occasionally complanated and ancipitous. The stems of the lateral branches are filiform and cylindrical; but in a well grown individual their basal portions are minutely denticulated by the scars of fallen leaves. The specific name comes probably from this character. A good-sized frond measures 30–35 cm. in height, with the lateral branches as long as 3–6 cm.

The basal leaves are spatulate or lanceolate with a short, complanated petiole. Those on the embryonal shoots are thick, mostly entire or undulating at the margin; but those above a short distance from the base are coreaceous, pinnately dentated, and evidently retrofractive; an elevated midrib runs almost to the apex. The edges of the complanated petiole run upwards into the ridges of the triquetrous stem and are often remarkably pronounced.

The leaves on the lateral branches are linear, alternately pinnately dentated, with a rib that runs undulating along the median line. The laciniae are more or less obliquely triangular, often, however, linear-subulate or truncated, and not seldom duplicatoserrated. The sinu are round and deep reaching almost to the rib. In the lower lateral branches the leaves are much smaller and approximately disposed. In most cases no obvious subordinate ramuli are seen on the lateral branches; but if one develops to any degree, the leaflets on it are linear-spatulate or clavate, attenuated below into long petiole, subentire at the margin and with an evident rib.

Vesicles are found solitary near the insertion point of a lateral branch. They are elliptico-spherical, with or without cryptostomata, and mucronated or crowned with a simple serrated leaflet on the apex. The stipe is usually shorter than the length of the vesicle.

Receptacles are obovate or elliptical, complanated with an-cipitous edges, more or less concave on one surface and convex on the other; the apical, occasionally the whole, margin is minutely toothed. They are usually found solitary at the axil formed by a leaf and the stem of a lateral branch, but sometimes two or three of them, each accompanied by a leaflet at its base, are borne racemously on a poorly developed minor ramulet.

var. stipulata YENDO. Prelim. List of Fuc. Jap. p. 158.

Plate XV. Fig. 18-21.

= *Sargassum micracanthum* J. Ag.: Anal. Alg. Cont. III. p. 52.

Diagnosis. Foliis fulcrantibus late stipulatis, stipulis margine dentatis sursum marginibus rachidis confluentibus.

Remark on var. *stipulata*. This variety has several noteworthy characters which enable us to distinguish it from *var. typica*. If only extreme forms of both varieties were compared, it would doubtless seem to be improper to range them under the same species. On comparing a large number of specimens, however, the characters to distinguish both varieties are often hardly detectable and they may be connected by various intermediate forms.

In this variety the basal portion of the complanated petiole of a fulcrant leaf is enormously expanded, with irregular dentation on the outer margins, and gives an appearance of stipules (fig. 20). The margins of the "stipules" become confluent with the

edges of the stem and traverse longitudinally up to the next node. Hence the edges are usually remarkably winged.

From the upper surface of the stipulated portion of a petiole a pair of opposite leaves start out. These leaflets are almost sessile and have a common insertion. From a point practically between the pair a lateral branch is given off. In comparison with other species these two leaves represent two unusually contracted basal nodes of a lateral branch. In the upper portions of a frond one of the pair is found at the base of the branch and the other a little above the first, but set in the opposite direction, thus clearly proving the above remark.

The leaves, except the basal ones, are dotted with prominent cryptostomata. In some specimens, however, this character is slightly developed, showing a gradual approach to *var. typica*.

Remark on the affinity. J. AGARDH at first doubted the validity of *Halochloa micracantha* KÜTZ. and referred it to *Sargassum Fengeri*, though with hesitation. In Anal. Alg. Cont. III. p. 52 he changed his former opinion and mentioned KÜTZING's plant as a distinct species under the genus *Sargassum*. He further noted that the species stands close to both *Sargassum Horneri* and *Sargassum tortile*.

In describing *Sargassum micracanthum*, J. AGARDH mentions the wings on the stems and the cryptostomata on the leaves as important characters. These are very pronounced in *var. stipulata* while almost negligible in *var. typica*. One of the specimens collected by Dr. Y. YABE on Tsushima Island was wingless on the stem and showed every other character of *var. typica*, but had well-defined cryptostomata on the laciniae of the leaves.

That the resemblance of the present species to *Sargassum Horneri*, *Sargassum filicinum*, *Sargassum tortile*, etc., is merely

superficial is satisfactorily proved by the receptacles. *Sargassum kiushianum* is the only species which is closely related to the present in many respects. These two, however, may be easily separated by the shape of the leaves, the texture of the fronds, etc.

Localities: *var. typica*: Tsushima Prov. (Y. YABE, HERB. SC. COLL.); Nagato Prov. (!); Iwami Prov. (J. NIKAI, HERB. SC. COLL.); Izumo Prov. (!); Tango Prov. (!); Sado Prov. (!); Hakodate (!); Rikuzen Prov. (!); Boshu Prov. (!); Shima Prov. (H.S.A.); Kii Prov. (!); Awa Prov. (!); Tosa Prov. (H. YAMAMOTO) (!); Hiuga Prov. (!); Kudō (H.S.A.), Fukuyama (H.S.A.), Oshima Prov.

var. stipulata: Ugo Prov. (!); Rikuzen Prov. (!); Sagami Prov. (H.S.A.).

Sargassum nigrifolium YENDO.

Plate XVI. Fig. 1-3.

Prelim. List of Fuc. Jap. p. 158.

Diagnosis. Radice nodoso-prostrata, pluribus frondibus ex superficie exeuntibus; caule communi brevissimi mox ramoso plerumque radici confluenti; ramis triquetris, alterne complanatis, ramulis e margine spiraler egredientibus; ramulis tenuioribus, teretibus, triquetris, foliis approximatis; foliis fulcrantibus verticalibus, crassis, cartilagineis, lanceolatis vel ovatis, immerse costatis, plerumque obliquis, petiolis complanatis, ramulorum lanceolatis vel clavatis, evanescente costatis; vesiculis subcompressis, ellipsoideis, mucronatis vel subulatis; receptaculis spatulatis vel subcuneatis, complanatis, apice minute dentatis, in axilla ramulorum solitariis, vel in brevissimo ramulo racemosis.

Description of the species. The root is a prostrate rugose mass with a number of shoots rising multicapitally from the surface. From the very base of each shoot, many protuberances are sent out confusedly, some of which elongate upwards into the principal branches. As a consequence the root of a well

developed plant has a very intricate appearance, and is likely to be mistaken for a sort of holdfast. The shoots, i.e. the axial stems, seem to develop very slightly, attaining not more than 1–2 cm. in height. Their stems are virtually smooth and cylindrical but have an irregular knotty appearance owing to the protuberances above noted.

The principal branches play the main part of a frond and in a well-grown individual may measure 2–2.5 feet in total length. The stem at the lower portion of a principal branch is essentially triquetrous with the leaves spirally disposed on it, the angle of their divergence being $\frac{1}{3}$. This, however, is not readily recognized as the stem is more or less twisted. From the insertion point of each leaf there passes downwards a prominent, almost wing-like ridge, to the lower third insertion. Hence the stem becomes complanated with the successive internodes compressed, by the twisting of the stem, in different planes.

Leaves on the principal branches are thick, cartilaginous, and dark olive-brown in colour even in the fresh condition. They are simple, obliquely spatulate or hemiphyllous, evanescently costated, attenuating and recurving downwards to a compressed petiole. The margin is absolutely entire. The lamina of a leaf is disposed perpendicularly and the petiole is horizontally flattened. No cryptostomata are seen.

The lateral branches appear after the principal branches have attained their full length. They are axillary, and not more than 3–4 inches in length. Their stems are thinner than the principal branches but have similar characters; and the leaves on them are much narrower, being obliquely cuneate or lanceolate, attenuated toward the base.

Vesicles are subcompressed, elongato-elliptical, mucronated

or with a short ligule which often runs downwards for a short distance forming a narrow wing-like appendage. They are usually found solitary on the basal portion of a lateral branch but not infrequently at the base of a minor fertile ramulet.

Receptacles are spatulate or subuncate, complanated, with ancipitous margin, and with a few dentations at the apex. They are, as in the preceding species, mostly solitary at each axil formed by a leaf and the stem of a lateral branch, but often 2-3 or more of them are racemously disposed on an extremely short ramulet.

Remark on the affinity. The present species has very well marked characters and no other species hitherto known to us seems to be closely related to it. The receptacles, however, suggest that this species should be placed near *Sargassum micracanthum*.

Localities : Misaki, Sagami Prov. (!); Izu Prov. (!); Iwami Prov. (!).

EUSARGASSUM J. AG.

Tribe 1. CARPOPHYLLÆ J. AG.

Sargassum graminifolium Ag.

Plate XVI. Fig. 4.

Spec. p. 18.—*Id.*: System. p. 209.—J. AG.: Spec. I. p. 303.—*Id.*: Spec. Sarg. Austr. p. 81.—Kütz.: Spec. p. 615.—*Id.*: Tab. Phyc. XI. Taf. 28. fig. 1.—DE TOXI: Syll. Alg. III. p. 38.

=*Fucus graminifolius* TURN.: Hist. Fuc. Vol. IV. p. 32. Tab. 210.

=*Sargassum Vachellianum* GREV.: Alg. Orient. p. 204. Tab. IV.

Remark on the determination. We have several specimens which accord with the descriptions and figures of the above named species as given by various writers. In our specimens, the stems on the upper portions of fronds are compressed and ancipitous,

measuring 3–5 mm. in breadth; and the vesicles are found mostly solitary near the base of the lateral branches. These characters accord especially well with the illustration given by TURNER in Hist. Fuc. l. c.

I have not seen any reproductive organ on our specimens. A fragmentary piece of a plant which has various characters referrible to *Sargassum serratifolium* or its allies, was collected at Shishikui, Awa Prov. Its receptacles, however, proved the plant to belong to the *Carpophyllæ*; and the vesicles on it were apiculated, or coronated with somewhat broadened leaflets (Pl. XVI. fig. 4). As we have not been able to find in Japan any species, except the present, which might be included in that tribe, I have provisionally connected the fragment with the plant above remarked upon, though not without considerable doubt.

Localities: Nemoto, Boshū Prov. (H. S. A.); Enoshima, Sagami Prov. (!); Shimoda, Izu Prov. (!); ? Shishikui, Awa Prov. (!).

Tribe 2. *GLOMERULATÆ* J. AG.

There are at least three species of plants within our boundaries which should be enumerated under the tribe *Glomerulatæ*. They are exclusively from the warmer regions and are more or less related to *Sargassum duplicatum* J. AG. But the exact characters of the last mentioned species, as well as its relationship to other allied members are not very clear to me. I can not but repeat what was said by Major REINBOLD¹⁾ when he described the *Sargassum* of the East Indies, viz.:—“Ohne Kenntniss der schwer zu beschaffenden Original-Exemplare, auf welche J. AGARDH die oben angeführten Arten basirt hat, lediglich aus

1) Sarg. v. Ind. Arch. p. 71.

den gegebenen Diagnosen und Bemerkungen heraus, dürfte es sehr schwer halten, *S. duplicatum* J. Ag. genügend sicher und scharf von den ähnlichen Arten zu unterscheiden."

I was especially careful in determining our plants but the result was not very satisfactory, as might be expected from the above noted circumstance. A few of the specimens were sent to Major REINOLD. He was kind enough to take the trouble to compare them with the reliable specimens at his command and has given me much valuable advice together with authentic specimens of BORY, GRUNOW, etc. The determination of the following three species is for the most part based on his opinion.

I have a few other specimens, sterile and fragmentary, which should probably be counted in this tribe. They are however so incomplete as to make impossible even to speculate upon their relation to any known species. We have reason to believe that a careful research in the warmer regions of Japan may add to her flora a few other species of *Sargassum*, especially of the present tribe.

Sargassum Illicifolium var. *duplicatum* J. Ag.

Plate XVI. Fig. 5-9.

Spec. Alg. I. p. 318.—REINB.: Sarg. v. Ind. Arch. p. 70.

=*Sargassum cristatofolium* HARV.: Alg. Felf. in Hook. Lond. Journ. Bot. I. p. 147. (sec. J. AG.).

=*Sargassum Pfeifferæ* GRUN.: Fidsch. p. 5.

Remark on the determination. Our specimens answer very well to the description of the above named variety given in J. AGARDH'S Spec. Alg., l. c. They also accord most satisfactorily with *Sargassum Pfeifferæ* GRUN., a part of an original specimen

of which I have obtained through the kindness of Major REINBOLD. The leaves in the present plant are soft and membranaceous, sometimes “duplicated” but often not, and turn a brownish colour on drying. The receptacles are less densely aggregated and are frequently isolated by a short stalk, partly exhibiting a character of the *Biserrula*. Dentated and smooth receptacles are mingled together in the same individual or even in the same ramulet. These points remind one of *Sargassum oocyste* var. *conduplicatum* J. AG. (in Spec. Alg. I. p. 317, but struck out in Sarg. Austr.).

J. AGARDH established a new species in Sarg. Austr. p. 90, calling it *Sargassum duplicatum*, reducing *Sargassum Ilicifolium* var. *duplicatum*, *Sargassum cristæfolium* HARV. and *Sargassum Pfeifferæ* GRUN. to the synonyms. It is very doubtful, however, whether the plant on which the new species was based is identical with all of the synonymized species. There is reason to believe that the plant probably differed from *Sargassum Ilicifolium* var. *duplicatum* as he says:—“Folia ad basem vix sunt excisa, hinc in vicinia *Sargassum Ilicifolia* vix disponenda; folia in hac præterea sunt multo tenuior, fere membranacea dicenda,” I prefer to retain here the old name as has been done by REINBOLD.

A specimen from Kashiwajima in Tosa Prov., has all its characters similar to the plant in question, except that the receptacles are never separated from one another by the stalk and are minutely spinulated without exception. It is a ♂. Unfortunately we have only one fragmentary piece and further discussion is impossible at present.

Localities: Hiratsuka, Sagami Prov. (!); Tosa Prov. (H.S.A.). Boshū (OKAMURA) (!).

Sargassum cristafolium Ag.

Spec. p. 13.—*Id.*: System. p. 297.—J. Ag.: Spec. Alg. I. p. 325.—*Id.*: Spec. Sarg. Austr. p. 91.—REINB.: Sarg. v. Ind. Arch. p. 70.—DE TONI: Syll. Alg. III. p. 52.—YENDO: Prelim. List of Fuc. Jap. p. 158. (*excl. syn.*).

?=*Sargassum duplicatum* BORY: Voy. Coquil. No. 22.

In 1900, I found a *Sargassum* species in Hiuga Prov., which had thick, leather-like, "duplicate" leaves and seemed to answer to the remark on *Sargassum cristafolium* given by REINBOLD in Sarg. v. Ind. Arch. p. 71. Unfortunately my specimens were all sterile, and as I was not without doubt about the species, one of the specimens was sent to the author of the above mentioned paper for examination. He kindly examined the specimen, compared it with the authentic specimens kept in BINDER's herbarium, and wrote me that the plant I had sent him was referrible, though provisionally, to *Sargassum cristafolium* Ag. and that it had a close resemblance to *Sargassum duplicatum* BORY., as well as to *Sargassum cristafolium* var. *Upolense* GRUN.

J. AGARDH¹⁾ refers, with some degree of doubt, *Sargassum duplicatum* BORY. to his *Sargassum beriberifolium*. The relation between the two species will be discussed under the next species.

Localities: Bindare Isl., Hiuga Prov. (!); Numazu, Suruga Prov. (H.S.A.).

Sargassum beriberifolium J. Ag.

Plate XVI. Fig. 10-14.

Spec. Alg. I. p. 337.—*Id.*: Spec. Sarg. Austr. p. 90. Tab. XXVI. fig. V.—DE TONI: Syll. Alg. III. p. 50.

1) Spec. Sarg. Austr. p. 123.

?=*Sargassum cristæfolium* var. *condensatum* SOND.: Alg. Trop. Austr.
p. 42. No. 15.

?=*Sargassum duplicatum* OKAM.: Enumer. Alg. of Jap. p. 153.

Remark on the species. Numerous specimens of marine algæ were brought home by Dr. H. HATTORI of the Botanical Institute, collected by himself while on a trip to the Bonin Islands. Among them there are a good number of *Sargassum*, all fertile and complete. After careful examination they all proved to belong to a single species, to which the descriptions and figures of *Sargassum beriberifolium* given by J. AGARDH in the papers above referred to were exactly applicable. As the establisher of the species seems not to have had access to a complete specimen, some additional remarks on the points which escaped his observation will not be superfluous.

The root is disc-shaped in a young and isolated individual but is usually prostrate, sometimes overlapping the surface of a *Lithothamnium* and eventually assuming a hemispherical or tuberculate shape of irregular outline. On its upper surface there stands in most cases several principal stems which are cylindrical, smooth and hardly a centimeter in height. A number of principal branches are sent out in all directions around the short stem, frequently apparently multicipitally. These branches play the important part of frond and attain 3–4 feet in length when fully developed.

The stem of a principal branch is complanated, giving rise to the lateral branches on its ancipitous margins distichously and alternately. But as the stem is generally more or less loosely twisted the arrangement is in some degree disturbed.

The leaves on the lower portions of the principal branches are elliptical or oblongo-obovate, evanescently costated, and sharply

but coarsely subduplicately dentated on the margin. Some of the leaves on the lateral branches are evidently "duplicated" while the larger number of them are simple.

Vesicles are spherical with a complanated stipe as long as their diameter. In the majority of cases those on the lower portion of a frond are marginated or even have coarsely dentated wings.

Remark on the synonymy. J. AGARDH¹⁾ has referred *Sargassum cristafolium* var. *condensatum* SOND. and *Sargassum duplicatum* BORY to the present species though with hesitation. On comparing our plant with a specimen of the former variety, determined by GRUNOW, it seems to me that J. AGARDH had good grounds for doing so. As for *Sargassum duplicatum* BORY, Major REINBOLD wrote me that it is very likely a species distinct from the present.

Mr. OKAMURA reported *Sargassum duplicatum* J. AG. to have been collected in the Bonin Islands. Dr. HATTORI observed that no other species seemed to occur there beside that which he had collected. It is not impossible that there occurs *Sargassum Illicifolium* var. *duplicatum*, which may have been mentioned by Mr. OKAMURA under the name *Sargassum duplicatum* J. AG. At present, however, I can only mention his statement here, though I doubt if his plant can be identified with *Sargassum beriberifolium*.

Locality. Bonin Isl. (HATTORI), ? (OKAMURA).

Tribe 3. *BISERRULÆ* AG.

Sargassum heterocystum MONT.

Cent. III. No. 54.—*Id.*: Voy. Bonite. p. 43. Tab. 142.—J. AG.: Spec. Alg. I. p. 346.—*Id.*: Spec. Sarg. Austr. p. 93.—DE TONI: Syll. Alg. III. p. 55.

1) Spec. Sarg. Austr. p. 90 and 123.

=*Carpacanthus heterocystus* Kütz.: Spec. p. 623.—*Id.*: Tab. Phyc. XI. Taf. 40.

? = *Sargassum armatum* J. Ag.: Spec. Alg. I. p. 313.—Kütz.: Spec. p. 626.

Our plant is sterile, but satisfactorily accords with the descriptions of the present species. The stems in ours are spotted with conspicuous cryptostomata and seem muricated on drying. The vesicles are glandulated and frequently have minute spinous processes on the surface.

Locality. Loochoo (K. MIYAKE, H. SC. COLL.).

Sargassum brevifolium Kütz.

Spec. Alg. p. 608.—*Id.*: Tab. Phyc. XI. Taf. 4. fig. 2.—DE TONI: Syll. Alg. III. p. 117.—HEYDRICH: Algflora v. Ost-Asien. p. 288.

A specimen of *Sargassum* sent me by Mr. SAITO for determination, answered very well to the description and illustration of the species mentioned above. Unfortunately the specimen was sterile and fragmentary, so that I am unable to add anything to the original remarks. The systematic position, therefore, is not certain, and I am compelled to follow the opinion of DE TONI¹⁾ who notes that the present plant seems to stand near *Sargassum heterocystum*.

Localities: Loochoo (WARBURG, HEYDRICH); Nagasaki (TILESIUS, KÜTZING); Misaki, Sagami Prov. (SAITO).

Sargassum biserrula J. Ag.

Spec. Alg. I. p. 318.—*Id.*: Spec. Sarg. Austr. p. 94. Tab. XXVII. fig. 4.—Kütz.: Spec. p. 626.—DE TONI: Syll. Alg. III. p. 58.—HEYDRICH: Algflora v. Ost-Asien. p. 287.—OKAM.: Enumer. Alg. of Jap. p. 154.

= *Sargassum squarrosus* GREV. in Ann. and Mag. of Nat. History. III. p. 254 and in Trans. Bot. Soc. Tab. XI.

? = *Sargassum distichum* SOND.: Plant. Preiss. p. 15.

1) Syll. Alg. III., l. c.

HEYDRICH reports the present species from the Bonin Islands as well as from Formosa. For the reason given under the head of *Sargassum beriberifolium* (p. 135), the occurrence of this species at the Bonin Islands seems to me rather doubtful.

Locality. Bonin Islands (WARBURG, HEYDRICH).

Sargassum cinctum J. Ag.?

Plate XVI. Fig. 15-16.

Spec. Alg. I. p. 324.—*Id.*: Spec. Sarg. Austr. p. 95 Tab. XXVII. fig. III.—KÜTZ.: Spec. Alg. p. 627.—DE TONI: Syll. Alg. III. p. 59.

?=*Sargassum acanthicarpum* GREV. Alg. Orient. in Ann. Mag. of Nat. Hist. II. p. 432 Tab. XIII. and in Trans. Bot. Soc. Edinb. Tab. VIII.

=*Sargassum odontocarpum* SONN.: Alg. Trop. Austral. p. 43. No. 16.

A fragmentary but fertile specimen, cast ashore in Hiuga Prov., exhibited characters of the present species, so far as they went. As the specimen lacks the lower portion, I am not able to refer it to any of the formæ which have been described by GRUNOW¹⁾ under this species.

Locality. Takamatsu, Hiuga Prov. (!).

Sargassum microphyllum Ag.?

Plate XVI. Fig. 17.

Spec. p. 33.—*Id.*: System. p. 306.—J. Ag.: Spec. Alg. I. p. 312.—*Id.*: Spec. Sarg. Austr. p. 99.—DE TONI: Syll. Alg. III. p. 71.—YENDO: Prelim. List of Fuc. Jap. p. 159.

?=*Sargassum Gaudichaudii* MONT.: Voy. Bonite. p. 47 Tab. 141.—KÜTZ.: Tab. Phyc. XI. Taf. 39.

?=*Carpacanthus Gaudichaudii* KÜTZ.: Spec. Alg. p. 632.

Remark on the determination. Our plant has much external resemblance to the plant identified with *Sargassum heterocystum*

1) In Proc. Alg. Vetter Pisani, etc. Cf. DE TONI: Syll. Alg. III. p. 60 *et seq.*

Mont. in the present work, but is rather to be referred to the species here mentioned. The leaves of this plant are not oblique, as in *Sargassum heterocystum*, and the vesicles are generally much smaller. The receptacles are triquetro-cylindrical, verrucose, and each separated by a short stalk. Had not J. AGARDH¹⁾ remarked that the receptacles on the upper portion of the fronds of the present species were poorly spinulated, I should not have hesitated to include our plant under the section *Malacocarpiceæ*. It is to be noted that the elevated cryptostomata on the softer parts of the stems, leaves, and often on the receptacles, give a spinulose appearance to these parts in a dried specimen.

Locality. Loochoo (K. MIYAKE, H. SC. COLL.).

Sargassum microcystum J. Ag.

Spec. Alg. I. p. 323.—*Id.*: Spec. Sarg. Austr. p. 94 Tab. XXVIII. fig. 1.—Kütz.: Spec. Alg. p. 608.—*Id.*: Tab. Phyc. Bd. XI. Taf. 6. —De Toni: Syll. Alg. III. p. 57.

I have only one sterile specimen, collected at Bindare, Hiuga Prov., and which exactly agrees with descriptions of the present species. Our plant has the leaves somewhat narrowed above, but the characteristic sharp and rich dentation on them is perfectly manifested.

Locality. Hiuga Prov. (!).

Tribe 4. FRUTICULIFERÆ J. Ag.

The following four species of this tribe have hitherto been assigned to the Japan coast. Their specific limits are by no means very clear. Besides, there exist several species of *Acantho-*

1) Spec. Sarg. Austr. p. 99.

carpicar, which have a close resemblance to them in the vegetative organs. Hence it is very often beyond our power to determine a sterile specimen of these species without more or less uncertainty. In addition to the specimens reported below, I have a few others which, owing to their incomplete state, can not be referred to any of the species, though they undoubtedly stand in near relation to one or the other of the latter. I therefore omit mentioning those incomplete specimens any further, reserving them for future study.

Sargassum aquifolium Ag.?

Plate XVI. Fig. 18-19.

Spec. p. 12.—*Id.*: System. p. 297.—J. Ag. Spec. Alg. I. p. 330.—*Id.*: Spec. Sarg. Austr. p. 102.—Kütz.: Spec. Alg. p. 607.—*Id.*: Tab. Phyc. Bd. XI. Taf. 3.—REINH.: Sarg. Ind. Arch. p. 73.—DE TOXI: Syll. Alg. III. p. 75.

=*Fucus aquifolius* TURN.: Hist. Fuc. Vol. I. p. 112, Taf. 50.

=*Sargassum virescens* FIG. et DE NOT.: Alg. Mar. Rosso. p. 21.—ZANARD.: Pl. Mar. Rubr. p. 239.

Remark on the species. Our specimen is the upper portion of a fertile plant. The basal leaves and other characters of the lower portion are not known. So far as the specimen reveals, the axial stem is smooth and filiform, sending out lateral branches in all directions. The leaves on the branches are thin but rigid, obovate or oblong, often more or less oblique at the base, and are frequently duplicato-serrated on the margin. The ribs are delicate but evident, disappearing above at the middle of the leaf length. Leaves on the ultimate ramulets are spatulate with acute dentations. Vesicles elliptical, unarmed, some of the younger ones glandulated, with compressed stipe nearly as long as the vesicles. Receptacles axillary, subcylindrical, sessile, often furcate, somewhat verrucose, and cymoso-racemose on a short ramulet.

Our specimen seems to accord pretty well with the diagnosis of *Sargassum aquifolium* Ag. The species is defined as having a complanated stem and repando-dentated leaves. These characters, however, can not be tested in our specimen as it lacks the lower portion of the frond. REINBOLD¹⁾ states that the fact that the ribs are nearly entirely wanting or are scarcely visible clearly characterizes the leaves of *Sargassum aquifolium* Ag. Other writers also agree in describing the plant as having semi-ennervous leaves or subevanescent ribs on the leaves, while KÜTZING delineates the ribs very clearly in his Tab. Phyc., l. c.

I cannot but mention with query the present species as occurring in our region, as the specimen on hand is fragmentary. Anyway it is plain from the specimen that a species belonging to the tribe *Fruticulifera* and closely related to this species, should be added to the algal flora of Japan.

Locality. Izu Prov. (K. TAXI) (!).

Sargassum obtusifolium J. Ag.

Spec. Alg. I. p. 339.—*Id.*: Spec. Sarg. Austr. p. 103.—MARTENS: Preus. Exped. Tange. p. 116.—DICKIE: Alg. Jap. in Journ. Linn. Soc. Bot. XV. p. 449.—DE TOXI: Syll. Alg. III. p. 79.—*Id.*: Phyc. Jap. Nov. p. 45.—OKAM.: Enumer. Alg. Jap. p. 156.

I doubt the occurrence of this species within our boundary.

Localities: Nagasaki (SCHOTTMÜLLER, MARTENS); Akashi channel (MOSELEY, DICKIE).

Sargassum latifolium J. Ag.

Spec. I. Alg. p. 336.—*Id.*: Spec. Sarg. Austr. p. 103.—DE NOT: Alg. Mar. Rosso. p. 18.—DE TOXI: Syll. Alg. III. p. 78.—O'KUNTZE: Revisio von Sarg. p. 217.

1) Sarg. v. Ind. Arch. p. 74.

= *Fucus latifolius* TURN.: Hist. Fuc. Tab. 94.

= *Sargassum polycarpum* DE NOT.: l. c. p. 17.

= *Sargassum subrepandum* KÜTZ. Tab. Phyc. XI. Taf. 2. MARTENS:
Preus. Exped. Tange. p. 129.—CF. DE TONI: Phyc. Jap. Nov.
p. 45 No. 172.

Remark on the species. MARTENS¹⁾ reports *Sargassum subrepandum* FORSK., collected at Nagasaki by SCHOTTMÜLLER. He mentions KÜTZING's Tab. Phyc., l. c., fig. 1, as an illustration of FORSKAL's species and not of *Sargassum subrepandum* AG. J. AGARDH²⁾ refers KÜTZING's illustration to the present species. As I have never seen any specimen regarded as authentic by any of these writers, I can only follow J. AGARDH's opinion.

MARTENS³⁾ assigns also *Carpacanthus latifolius* KÜTZ. to Nagasaki. But J. AGARDH⁴⁾ discredits the presence of any *Carpacanthus* structure in the receptacles of *Sargassum latifolium* J. AG. If MARTENS had mentioned *Carpacanthus latifolius* KÜTZ. after identifying his specimen with the illustration in Tab. Phyc. Bd. XI, Taf. 47, the specimen might possibly have been a basal portion, or a young sterile frond, of *Sargassum serratifolium* or of one of its allies.

Localities. Nagasaki (SCHOTTMÜLLER, MARTENS); Japan (O'KUNTZE).

Sargassum assimile HARV.

Plate XVII. Fig. 2-3.

Charact. of New Alg. p. 328.—DE TONI: Syll. Alg. III. p. 39.—*Id.*:
Phyc. Nov. Jap. p. 46.—OKAM.: Enumer. Alg. of Jap. p. 152.—
YENDO: Prelim. List of Jap. Fuc. p. 159.

Description of the species. A specimen, collected at Naga-

1) Preus. Exped. Tange. p. 116.

2) Spec. Sarg. Austr. p. 103.

3) l. c., p. 130.

4) Spec. Sarg. Austr. l. c.

saki in May 1879 and kept in the herbarium of the Science College of Tokyo, accords pretty well with the original diagnosis and the photograph of the authentic specimen of the above mentioned species. The species was rather briefly defined and as no comment on it nor a figure of it has since been given, the following observations on our specimens may not be superfluous.

The specimen in the herbarium lacks the root, but seems to have been cut off quite near the base. The total length of the specimen is about 30 cm. The stems of the principal branches are cylindrical and smooth, gradually tereto-compressed above and subpinnately or vaguely ramosc. The leaves on the principal branches, i. e., the fulcrant leaves, are oblongo-spathulate, generally oblique at the base and blunt at the apex; the ribs are hardly elevated above the surface of the laminae and appear as obscure dark streaks running longitudinally in the median line. In most cases they reach quite to the apex of the leaf, but sometimes become evanescent above. The leaves on the lower portion of the frond are frosted with a few rows of cryptostomata, but the upper narrow ones have only a single row of them on each side of the rib; margins, sparingly dentated, with each tooth subapiculated; substance of leaves, thin and membranaceous, turning yellowish brown on drying.

The vesicles are spherical, rounded at the apex and mostly margined. They are found solitary at the base of each lateral branch. Those found on the upper portion of the fronds are evidently glandulated; but in the second specimen, collected in Kii Prov. by the writer, they were entirely unspotted. The stalks are from a half to a whole length longer than the diameter of the vesicle, dilatated upward so as to become confluent with the marginal wings, if any, of the vesicle.

The reproductive organ is not developed in our specimens.

var. stipulata YENDO.

Plate XVII. Fig. 2-3.

Prelim. List of Jap. Fuc. p. 160.

Diagnosis. Petiolis foliorum complanatis, ancipitibus, alatis, marginibus acute dentatis.

Description of the variety. *Var. stipulata* has the petioles complanated with coarsely dentated wings along the ancipitous edges. In other respects as in the type.

Remark on the affinity. Our plants have a close affinity with that illustrated by KÜTZING in his Tab. Phyc. XI. Taf. 2, fig. 2, under the name of *Sargassum herbaceum*. J. AGARDH¹⁾ doubtfully referred KÜTZING's figure to *Sargassum aquifolium* AG. But this referring of KÜTZING's plant to AGARDH's could have resulted only from uncertainty as to the specific conception of the latter. REINBOLD²⁾ has already pointed out this matter in full.

The present species belongs without doubt to the "latifolium" type; but none of the species under this type are by any means well defined, as may be seen from REINBOLD's remarks. The present species has also a certain resemblance to a form of *Sargassum ilicifolium* J. AG. The latter is, indeed, very hard to separate from the species of the "latifolium" type when sterile. It is, therefore, very probable that HARVEY's species may be reduced to some of the known species of the type mentioned, and still more probable that *var. stipulata* should not be placed under the present species but under some other. These are highly interesting problems which ought to be solved in the future. It

1) Spec. Sarg. Austr. p. 102.

2) Sarg. v. Ind. Arch. p. 74.

may be safely inferred that after careful researches on a large set of fertile specimens of these species we shall probably be able to strike off several from the list of those we at present include under the type.

Localities: Nagasaki (H. SC. COLL.) ; Kushimoto, Kii. Prov. (!)
var. stipulata : Tosa Prov. (!)

Tribe 5. CYMOSÆ. J. AG.

Sargassum vulgare AG.

Plate XVII. Fig. 4–5.

Spec. p. 3.—*Id.*: System. p. 293 *partim*.—J. AG.: Spec. Alg. I. p. 342.
 —*Id.*: Spec. Sarg. Austr. p. 108.—DE TONI: Syll. Alg. III. p. 85.
 = *Fucus natans* TURN.: Hist. Fuc. I. Tab. 46 (*excl. form. plur.*).
 = *Sargassum leptocarpum* KÜTZ.: Phyc. Gen. p. 362.—*Id.*: Spec. Alg.
 p. 608 ?

Remark on the species. So far as hitherto reported, *Sargassum vulgare* and its varieties seem to have been confined to the Atlantic Ocean and the Mediterranean Sea, and none of the members belonging to the tribe *Cymosæ* were ever thought to exist in our region. During the course of the present study, however, I have met with two specimens which seem to come under the limits of the above mentioned species.

I am not very familiar with *Sargassum vulgare* and its varieties, having had access to only a few specimens which bear that name. Yet I can not refrain from thinking that the species, taken in the sense of J. AGARDH, covers many widely divergent forms, so that some of the plants referred to by J. AGARDH as synonyms of the varieties can hardly be considered to belong to the same species. Here, however, I can not but dispose our plants according to the classification of the well known algologist.

var. linearifolium J. Ag. Plate XVII. Fig. 5.

Spec. Sarg. Austr. p. 108.—DE TONI: Syll. Alg. III. p. 86.

= *Sargassum vulgare* GREV.: Alg. Brit. Tab. 1.

= *Sargassum flavifolium* Kütz.: Spec. Alg. p. 615.—*Id.*: Tab. Phyc. XI. Tab. 26.

= *Sargassum megalophyllum* MONT.: Fl. d'Algerie. s. 1. f. 1.—Kütz. Spec. Alg. p. 615.—*Id.*: Tab. Phyc. XI. Taf. 23.

Remark on the variety. A fragmentary but fertile specimen, which accords very well with the descriptions and figures of *Sargassum megalophyllum* MONT., is kept in the herbarium of the Sapporo Agricultural College. The specimen was collected in the province of Tosa by MR. T. MAKINO. J. AGARDH placed MONTAGNE's species, i. e., together with two others under the present variety as above quoted. The accompanying figure (Pl. XVII, Fig. 5) shows a portion of the specimen in our hands, which is open to the criticism of those who are familiar with the present variety.

var. foliosissimum J. Ag. Plate XVII. Fig. 4.

Spec. Sarg. Austr. p. 108.—DE TONI: Syll. Alg. III. p. 86.

= *Fucus foliosissimus* LAMX.: Essai. Alg. Tab. VII. fig. 1.

= *Sargassum pteropus* Kütz.: Spec. Alg. p. 608.—*Id.*: Tab. Phyc. XI. Taf. 5, fig. 1.

= *Sargassum Bahiense* Kütz.: Alg. Spec. p. 608.—*Id.*: Tab. Phyc. XI. Taf. 5, fig. 2.

= *Sargassum trachyphyllum* Kütz.: Spec. Alg. p. 609.—*Id.*: Tab. Phyc. XI. Taf. 8, fig. 1.

= *Sargassum polyphyllum* Kütz.: Spec. Alg. p. 609.—*Id.*: Tab. Phyc. XI. Taf. 8, fig. 2.

= *Sargassum brevipes* Kütz.: Tab. Phyc. XI. Taf. 9 fig. 1.

Remark on the variety. A fragmentary but fertile specimen, kept in the herbarium of the Science College of Tokyo, has many points referable to *Sargassum Bahiense* Kütz., i. e. The

receptacles are well developed in the specimen and prove it to be a member of the tribe *Cymosæ*. J. AGARDH brought down KÜTZING's species to the present variety. But I can not be easily convinced by the opinion that such a plant as that in our hands, with such characteristic receptacles, should be united with *Sargassum vulgare* Ag., however considerable the variations which the latter may undergo. If our plant be exactly identical with KÜTZING's, the species *Sargassum Bahiense* KÜTZ., I believe, had better be restored.

Localities: *Var. linearifolium*; Tosa Prov. (H. S. A.).

Var. foliosissimum; Loochoo (K. MIYAKE, H. SC. COLL.)

Tribe 6. *RACEMOSÆ*. J. AG.

Sargassum Ringgoldianum HARV.

Plate XVIII.

Charact. of New Alg. p. 327.—J. AG.: Spec. Sarg. Austr. p. 57.—*Id.*: Anal. Alg. Cont. III. p. 51.—DE TONI: Syll. Alg. III. p. 22.—*Id.*: Phyc. Jap. Nov. p. 44.—OKAM.: Enumer. Alg. of Jap. p. 146.—YENDO: Prelim. List of Jap. Fuc. p. 156.

=*Sargassum coreanum* J. AG.: Spec. Sarg. Austr. p. 58.—*Id.*: Anal. Alg. Cont. III. p. 51.—DE TONI: Syll. Alg. III. p. 22.—OKAM.: Enumer. Alg. of Jap. p. 145.

Description of the species. The present species has several unique characters and is readily distinguished from all the other species. While it is yet very young, measuring some one or two feet in height, with the basal leaves still unfallen, the stem is compressedly triangular, ancipitous, usually not twisted, and sparingly serrated on the margins. The leaves are linear-spathulate, 4–6 cm. long 1.5–2 cm. wide, rounded at the apex and attenuated below, ending finally in a short ancipitous petiole. They grow alternately from the flat surface of the stems and are strongly

retrofractive, recurving and gently ascending. The strong retrofraction of the leaves gives a versatile appearance to the upper node (fig. 1.). The interfolial distances range from 2 to 7 cm. In substance the leaves are thick and coreaceous, with an elevated rib which dies away near the apex.

As the plant grows further, the lower portions of the ancipitous stem gradually become cylindrical, measuring 0.5-0.75 cm. in diameter. The basal alternate leaves drop off by degrees and their insertion points now appear as dilated and angulate elevations with apices like a chisel edge. The result is a stout thick stem bent more or less zigzag in a plane (fig. 3). The leaves and stems in the upper portions retain characters similar to those of the younger lower portions described above, and the leaves therein often attain a length of 37.5 cm. with a nearly equal breadth.

In a well developed plant the root is disc-shaped, elevated on the upper surface, usually conical but frequently hemispherical. The diameter at the base measures 2-3 cm.

Branches and branchlets are sent out from the upper surface of the flat petioles. The branches starting from the basal leaves become by further development indistinguishable from the primary stem, acting as the principal members of the frond. They ramify mostly in a plane, apparently in a dichotomous or subdichotomous way. Hence, a full-grown plant bears a considerable number of fastigate, stout branches, each richly provided with gigantic leaves. In total length a plant often measures 7 feet or more.

The vesicles are oblong ellipsoid, slightly compressed, with a comparatively short ancipitous stalk. Those on the sterile lower portions are more roundish and larger, coronated with a short

wing-like leaflet. They are often so large as to measure 3 cm. in length, 1.7 cm. in width, and 1.5 cm. in thickness. The vesicles on the upper branches as well as on the receptaculiferous ramulets are generally elongated and much compressed. The wings traverse the margin, continuous with the long linear leaflet at the upper end of the vesicle, and frequently with the flattened stalk at the lower end (Fig. 4,9).

The vesicles on the younger portions of a frond are mostly found solitary upon the petiole. But in a fully grown though not fertile individual, we frequently find a cluster of two or more vesicles with the "anlage" of a receptacular ramulet on each stalk.

Receptacles differ greatly in external shape and size according to the sexes. The male receptacles are linear-spathulate, rarely obliquely cuneate, foliaceous, minutely verruculose, often measuring 5 cm. long, 7 mm. wide, and 1 mm. thick; both ends are for the most part rounded, with a stalk 2-5 mm. in length at the base. They are paniculately disposed on an upper branchlet (fig. 6-8). The receptacles of female plants are compressed siliquaeform, much smaller in size, and measure 5-11 mm. long and 2-3 mm. wide. They are disposed in the same manner as male receptacles, but are more regularly paniculate; and usually a larger number are found on a ramulet (fig. 5).

Remark on the synonymy. HARVEY's original diagnosis sharply defines the present species. He says, however, that the branches are pinnate and the leaves decomponently pinnate. This description is hardly recommendable for such a plant as this, with strongly retrofractive leaves and branches, and is not applicable to well grown forms with fastigate branches.

J. AGARDH described a new species in Spec. Sarg. Austr. p. 58, under the name of *Sargassum coreanum*. He already

recognized the close relation between his species and *Sargassum Ringgoldianum* HARV., but did not observe the difference in full. Afterward, in Anal. Alg. cont. III., p. 51, he described a plant in detail which he identified with HARVEY's species. He seemed to have had great doubts on the validity of his species when he wrote the latter paper. The distinguishing point between his and HARVEY's species lay essentially in the characters of the receptacles. DE TONI¹⁾ also notes the strong resemblance of the two species when he says "Huic speciei (*S. Ringgoldianum* Harv.) paraffine videtur *Sargassum coreanum* J. AG." It is not hard to see from J. AGARDH's later publication²⁾ that he was very uncertain as to the propriety of describing them separately.

I have seen authentic specimens of neither J. AGARDH's nor HARVEY's species. I am, however, strongly of the belief that I am not in error in referring our plant to the above named species, which has no confusable form on our coast. The receptacles differ in external form according to the sex as described above. J. AGARDH's description of *Sargassum coreanum* I have found satisfactorily applicable to the female plants; while the description of *Sargassum Ringgoldianum* in Anal. Alg., l. c., applies very well to the male individuals. I therefore do not hesitate to say that J. AGARDH described the sexually differing forms of *Sargassum Ringgoldianum* HARV. as two distinct species.

The differences in the vegetative characters of male and female individuals are quite negligible. A difference, if any, will be found in the crown leaflets of the vesicles. In the male, abruptly truncated leaflets predominate, while in the other,

1) Phyc. Jap. Nov. p. 44.

2) Anal. Alg. Cont. III. p. 51-52.

sex, linear-elongated, acuminate ones do so. But this of course is not always strictly carried out.

Systematic position of the species. The present species has been placed under the subgenus *Bactrophycus* by J. AGARDH; but there seems to be no affinity between it and the remaining members of that subgenus except in the fact that the leaves are strongly retrofractive. The *Bactrophycus* is characterized by having each receptacle accompanied by a bractlet at its base; the terminal one or two only being free from any appendage. In this species, as described above, the receptacles are bractless from the beginning and are disposed in a raceme on an ultimate ramulet. This character suggests that the present species belongs to the tribe *Racemosæ* and should be placed near *Sargassum Henslowianum* J. AG.

Localities: Nagato Prov. (J. NIKAI, H. SC. COLL.); Tsushima Prov. (H. S. A.); Korea (CROUAN, J. AGARDH); Izumo Prov. (!); Tango Prov. (!); Sado Prov. (!); Shakubetsu (H. S. A.); Mouth of Amur River (FENGER, J. AGARDH); Kushiro Prov. (H. S. A.); Rikuzen Prov. (!); Hitachi Prov. (!); Bōshū Prov. (!); Izu Prov. (!); Shimoda (WRIGHT, HARVEY); Sagami Prov. (!); Shima Prov. (!); (H. S. A.); Awa Prov. (!); Iyo Prov. (!); Bungo Prov. (!); “Warmer parts of the Pacific coast of Japan” (OKAMURA).

Sargassum siliqosum J. AG.

Plate XVII. Fig. 1.

Spec. Alg. I. p. 316.—*Id.*: Spec. Sarg. Austr. p. 121, Tab. X.—Kütz.: Spec. Alg. p. 619.—DE TONI: Syll. Alg. III. p. 107.—*Id.*: Phyc. Jap. Nov. p. 45.—MARTENS: Preuss. Exped. Tange p. 116.

= *Sargassum ornatum* GREV.: Alg. Orient. in Ann. and Mag. of Nat. Hist. Vol. II. p. 205 Tab. IV. and in Trans. Bot. Soc. Edin. p. 87 Pl. VI.

Our specimen is sterile, but very well accords with the descriptions of this species. The leaves in the upper portions of the frond exhibit some monstrosity. The terminal parts of the leaves are swollen—the remaining parts undergoing no modification—to an obovate vesicle with the narrow end tapering downwards to become confluent with the rib. The accompanying figure (Pl. XVII, fig. 1) will explain much better than a description.

Localities. Nagasaki (SCHOTTMÜLLER, MARTENS) ; Kushimoto, Kii Prov. (!)

Sargassum sagamianum YENDO.

Plate XVII. Fig. 6–10.

Prelim. List of Fuc. Jap. p. 157.

Diagnosis. Radice primaria scutellata, adultiore nodoso-prostrata, pluribus frondibus ex facie multicapite exeuntibus; caule communi cylindræo verrucoso brevissimo mox ramoso; ramis exacte triquetris spiraliter alterne ramulosis, sæpe tortilis, ramulis ad orto retrofractis; foliis inferioribus lanceolatis vel spathulatis, immerse costatis, dentatis vel integris, mediis superioribusque anguste lanceolatis vel clavatis, ancipitibus, integerrimis, sæpe parce dentatis, crassis coreaceisque, nonnunquam secundis; vesiculis ellipsoideis vel pyriformibus, mucronatis vel aristatis, petiolis complanatis, in inferiore parte ramulorum solitariis; receptaculis.....

Description of the species. The present species has remarkably unique characters and is readily distinguished from others. Although a fertile specimen has not yet been found, I do not hesitate to give a new specific position to the plant. The root is disc-shaped while yet very young, but soon spreads horizontally, sending out a number of erect stems multicapitally from the upper surface. The stems of the decayed fronds are cleared from their bases, leaving knob-like protuberances on the prostrate

root. The result is an irregularly knotty mass as shown in Pl. XVII, fig. 6.

The stems of the shoots or the branches are triangular with sharp edges, with strongly retrofractive leaves spirally disposed. The leaves on the basal portions are lanceolate or spathulate, ancipitous or immersedly costated, and entire or sparingly dentated on the margins. Those on the upper portions are linear clavate, 2–4 mm. wide and 2–5 cm. long; in the typical plants the margins are entire but often coarsely denticulated. In substance the leaves on all parts are thick and coreaceous. Cryptostomata are entirely wanting.

Not infrequently the stems are loosely twisted and arched in the upper portions and send out the leaves in a second manner towards the convex side (fig. 10).

Vesicles are elliptical, measuring 4–5 mm. in diameter and 5–7 mm. in length. When fully grown they are mucronated or aristated at the top, and have a short ancipitous stipe at the base. They are found solitary near the base of a lateral branch or branchlet.

Receptacles unknown.

Remark on the systematic position. As our plant has not been found in fructification, the exact systematic position is uncertain. The present disposition is therefore a provisional one. It may be considered to have some resemblance to *Sargassum virgatum* AG. or *Sargassum concinum* GREV., but the angulate stems and the non-glandulated leaves do not accord with the description of either species.

Localities. Sagami Prov. (!) ; Shima Prov. (!) ; Hiuga Prov. (!) ;

Sargassum nipponicum YENDO.

Plate XVII. Fig. 11-16.

Prelim. List of Fuc. of Jap. 158.

Diagnosis. Radice fibrillosa, rhizinis¹⁾ longissimis, filiformibus; caule simplici, filiformi, undique ramis egredientibus; foliis lineari-clavatis, deorsum attenuatis, apice acutis, immerse subcostatis, superioribus ramorumque angustis sæpe subulatis vel hemiphyllodeis, integerrimis rarius bidentatis; vesiculis fusiformibus in inferiore parte ramulorum paucioribus; receptaculis cylindraceis breve petiolatis in ramulo abbreviato racemosis.

Description of the species. The root is fibrous, consisting of radially extending, filiform rhizines which are sent out from the very base of the frond without any obvious rule as to arrangement. As far as our specimen shows, the primary stem of a frond seems to be simple, that is, it does not ramify at the basal portion to give rise to the members which correspond to the principal branches of other species. But very often numerous shoots are found with their roots entangled together into a large mass.

Stem is 1-4 feet long, filiform, smooth, often slightly angulate, with short lateral branches spirally arranged on it. The basal as well as the fulcrant leaves are linear-clavate, gently attenuated below and acute at the apex. Some of the upper leaves are often subulate above and slightly hemiphyllous. Most of the leaves have a very insignificant immersed midrib. Leaf margin is generally entire, often undulating and frequently with one or two dentations.

The lateral branches are short, measuring a few inches in length, simple or slightly decompound, with a delicate, filiform stem. The leaves on them are narrowly lanceolate or filiform,

¹⁾ In the same sense as KJELLMAN used in "The Alge of the Arctic Sea." p. 238.

spirally disposed. Those on the ultimate branchlets are sometimes replaced by vesicles, but very frequently no vesicle is to be found in a frond.

Vesicles, if present, are narrowly spindle-shaped, 2–4 times longer than the diameter, attenuated towards both ends into a filiform stalk and an awn.

Receptacles are cylindrical, each with a short stipe at the base. They are disposed in a short raceme on an ultimate ramulet. Those on the terminal portion of a ramulet are generally simply geminate or solitary upon the petiole of a small subulate, bract-like leaflet.

Remark on the affinity. This species without doubt belongs to the subgenus *Racemosæ* J. AG. and should be placed near *Sargassum Henslowianum* J. AG. It resembles a form of *Sargassum hemiphyllum* in general appearance as well as in having the fibrous root. When fertile, however, each may be readily distinguished from the other; and when sterile, the present species is easily recognized by the coreaceous texture of the leaves.

Localities. Cape Shiomisaki, Kii Prov. (!); Hiuga Prov. (!)

ISHIGE¹⁾ Gen. nov.

Ishige Okamurai sp. nov.

Plate II. Fig. 1–8.

= *Pelvetia Babingtonii* OKAM. (nec HARV.). Alg. Jap. Exsic. No. 37.

—Id.: Enumer. Alg. Jap. p. 137.

= *Pelvetia Babingtonii* HARV.? YENDO: Prelim. List of Jap. Fuc. p. 151.

Diagnosis. Planta duabus formis; una forma radice scutellata rachide brevitereti, mox expansa, fronde complanata, regulariter decomposite dichotoma, flabellata, laciniis late linearibus, sursum latioribus, sinibus

1) From the Japanese name of the plant.

rotundis, apicalibus bifidis, cryptostomatibus numerosis; alter forma radice scutellata rachide brevi cylindracea decomposito-dichotome ramosa, lacinii inferioribus mediisque cylindraceis vel tereto-angulatis, sursum tenuioribus, apicalibus bifidis, cryptostomatibus nullis. Frons ex cellularum duobus stratis constructa, inarticulata; corticali cellulis minoribus antielinale dispositis, chromatibus, et interiori cellulis elongatis articulatis cylindraceis in reticulum densissimum nudique anastomosantibus, hyalinis. Receptaculis.....

Description of the species. This plant is one of the most common algae on the coast of the warmer regions of Japan. It is always found above low-water mark and is exposed to the air during the ebb-tide hours, sometimes lying in intensely hot sunshine and sometimes thoroughly washed by fresh rain water.

The plant has two forms of an entirely different appearance. One has all its segments, except in the aberrant cases remarked upon below, cylindrical or terete; while in the other they are flat and leaf-like. I shall call the former the "filiform" type and the latter the "foliose" type, for convenience sake.

The foliose type has scutellate root a few mm. in diameter, with one or more shoots arising from the same root. The stem is cylindrical, hardly attaining a few mm. in diameter at the base and soon expanding into a flabellate frond. The frond ramifies in a regularly dichotomous manner, unless an arm is checked in its development. The axils are wide with the sinu round; hence the appearance of an entire frond is fan-shaped. The segments are linear or linear-cuneate ranging from 5 mm. to 40 mm. in length and from 3 mm. to 20 mm. in width. Average thickness, ca. 0.6 mm. The apices of the ultimate segments are narrowed and bifid, and have a slit-like depression at each apical point, the longer axis of the depression being parallel to the surface of the segment. Occasionally we find a specimen of this type with an inflated segment containing gaseous matter in it. But the inflation is

never a constant character and is accidental. It is most frequently found in those plants which live on rocks at low-tide marking open seas.

Numerous sterile cryptostomata are found throughout the whole of the frond except in the basal cylindrical portions. They are globular in shape, situated just below the cortical layer, with a communicating opening through the latter. Hairs are given off from the bottom of the cryptostoma and extrude through the opening above the surface of the frond. In dried specimens the hairs appear as inconspicuous white specks on the dark brownish frond.

The filiform type has a scutellate root a few mm. in diameter, with one or more shoots starting from the same root. The stem is cylindrical measuring 1.-1.5 mm. in diameter and ramifies subregularly dichotomously with acute axils. The segments are cylindrical or terete, more or less compressed, and broadened at the point below each axil. They are similar in size and shape everywhere in a frond, except the ultimate ones which are much thinner and shorter. As the apical segments are pointed in this type, the slit-like depression found in those of the foliose type, now appears as an inconspicuous excavation. The substance of the frond is cartilaginous and the colour is dark brown while in the water, but turns black when exposed to the air. The total height of a frond often reaches 15 cm. Cryptostomata are wanting in this form.

It is quite common to find a branch of the foliose type in a part of a filiform frond. The foliose branches may be near the basal portion or at the middle of a filiform frond, and in most cases several of them occur close to one another in the same individual (Pl. II, fig. 3). This is due to the extraordi-

nary growth of abnormal branches which start out from the surface of an internode of the filiform segment. We could never find any segment in a normal filiform frond dilatated or complanated to such a degree as is found in a foliose frond; nor could we find any of the segments of the foliose branch narrowed to a cylindrical or terete one, except the basal portion which is inserted in the filiform segment. The point of insertion is more or less intumescend, which is probably never met with in the case of ordinary ramification (Pl. II, fig. 2-4). After carefully studying the nature of this foliose branch I have arrived at the conclusion that the abnormal branch was due to a parasitic organism (*Streptothrix*-like) invested in the frond.

The segments in the middle or the upper portion are often verruculose instead of smooth. By cutting these portions crosswise we find small ovate pits, in shape apparently the conceptacles of a Fucaceous alga. But so far as my observation extends nothing that could be suspected to be the reproductive cells of the present plant could be found in them. Nor could there be found any single hair growing from them. A large number of the pits, if not all, belong to the parasite.

Structure of the frond. The frond is constructed essentially of two parts, the medulla and the cortex. The medullary portion is composed of hyphal cells much entangled with one another so as to form a compact and elastic tissue. The cortical part is built up of rows of cubical cells disposed anticlinally. They are connected with the hyphal cells by the innermost ones which are much larger and more spherical than the peripheral ones. The cubical ones are rich in brownish chromatophores which give the frond a dark olive colour when fresh.

In the middle portions of the frond we find two sorts of the

hypheal cells. The one extends almost always longitudinally along the axial part of the frond and has a much thinner wall than the other. It is rich in contents and has transverse septa at intervals of certain distances. The other is much narrower than the axial ones and extends in all directions, occasionally running from one surface to the other, binding together the cortical layers. It is destitute of a septum throughout its entire length (Pl. II, fig. 6).

By cutting a longitudinal (meridional) section of a terminal segment of a well-grown plant through the depression at an apical point, we find in the middle a notch, around which numerous cells are aggregated without any obvious regularity. The cortical layer at the external margin is much thinner, being composed of 3-5-celled rows. The cells are smaller than those of the cortical layer of other portions of the frond and are radially elongated. The cells of the medullary portion are exclusively septated and loosely arranged. They are all alike, but those situated in the axial part are slightly larger in diameter than the neighbouring ones. The former mostly run longitudinally while the latter are directed obliquely outward and ramify simultaneously to join with the cortical cells (Pl. II, fig. 5).

The lower portions of the foliose type are terete or cylindrical, and have a structure similar to the complanated part in essential characters. The cortical parts in these portions, however, are nearly twice as thick and the cells in a row are 18-20, or nearly twice as many as in the complanated part. The hypheal cells are more compactly arranged, compressing one another with much thicker cell-walls.

The structure of the filiform frond is exactly similar to

that of the cylindrical portion of the foliose ones just alluded to. In some cases the upper segments are much complanated, more or less resembling the segments of a narrow form of the foliose type. The structure of such portions has no marked difference from that of the foliose type, except that the cryptostomata are entirely absent.

Relation between the two forms. Specimens of the filiform type have been distributed by MR. OKAMURA under the name of *Pelvetia Babingtonii* HARV., as No. 37 of "Algæ Japonicæ Exsiccatae." The foliose type was suspected by many people to belong to a different species from the filiform one and some went so far as to consider them to belong to different genera.

Those who consider the two forms to belong to different species are inclined to regard the foliose branches upon the filiform frond as a parasitic or symbiotic combination. The fact that one of the forms never partially reveals the character of the other stands strongly in favor of this view. A dimorphic plant may very often show an intermediate or mixed form. But in the present plant none of the ordinarily ramified segments of one type assumes the form of the other in any satisfactory degree. The upper segments of a filiform frond may be more or less broadened or complanated but never to such an extent as to link the two types; in like manner, the segments of the foliose type often considerably decrease its breadth but never entirely lose the characters of that type. When a branch with foliose segments is found in a filiform frond, it always starts from an internodal point with a peculiar mode of insertion, as has been already mentioned (Pl. II, fig. 3, 4).

I am, however, strongly of the belief that the two types belong to one and the same species. We have not been

able to find a case in which a frond of the foliose type was growing on any alga other than either of the two types under consideration. Repeated examinations have been made on sections through the adjoining points of the two forms. In every case it was revealed nothing except that the hypheal cells of the segment of the filiform frond passed into the stem of the foliose one without any indication that the two different forms belonged to separate plants. And in the case in which the abnormal foliose branches were found on a frond of the foliose type, the section through the point of insertion showed only a slight disturbance in the cortical tissue at that point, and nothing else. The two types will be regarded as the two forms of a dimorphic plant, though positive proof for doing so is lacking. The determination is, therefore, a provisional one to be held until it has been proved that the two types belong to different species.

The facts that the abnormal foliose branches, whether they be on a frond of the foliose type or of the filiform type, are always accompanied by the parasitic organism infesting the principal frond, and that they are found fasciculately at the same point, remind us of the witches' broom of a flowering plant. The malformations of *Ascophyllum* and *Cystoseira* have been reported by BARTON¹⁾ and VALLIANTE.²⁾ But in these cases no disturbance in the ramification of a frond was observed. We are familiar with the fronds of *Fusus evanescens*, which have numerous stunted branches growing at an internodal point or on

1) BARTON: Malformation of *Ascophyllum* and *Desmarestia*, in MURRAY, Phyc. Mém. Pl. II. p. 21.

2) VALLIANTE: Le *Cystoseirae* del Golfo di Napoli. Fauna n. Flora des Gofes von Neapel. 7.

a torn-off end.¹⁾ This is not, in many cases, a result of regeneration on a wounded part, but is a witches' broom caused by certain endophytic alga. In *Fucus evanescens*, however, differently from ours, the broom branches are similar in shape to the principal frond. It is a widely known fact that some flowering plants, such as *Abies*, *Euphorbia*, etc., when attacked by parasitic fungi, undergo a considerable modification in the mode of ramification as well as in the shape of the leaves. So far as the knowledge of the present writer extends, no example parallel to our case has ever been recorded from the algae. More details on this subject, I hope to present in another paper.

Systematic position of the species. On what grounds OKAMURA has identified this plant with *Pelvetia (Fucus) Babingtonii* HARV. is not satisfactorily clear to me; it might have been because this is the only plant on the Pacific coast of middle Japan, whose structure has a certain resemblance to *Pelvetia*. Judging from the remark made by him in Enumer. Alg. of Jap. p. 137, he seems to have laid too much stress on the locality of *Pelvetia Babingtonii* HARV. mentioned by the original author. And he seems to have believed the foliose type to belong to other species. There is very little ground for referring this species to the genus *Pelvetia*, but we have many points separating it from that genus.

The characters of the cryptostomata in foliose type exactly answer to those of the other Fucaceous genera hitherto studied (Pl. II, fig. 8). Cf. the figures of the cryptostoma of *Sargassum filipendula* newly illustrated by SIMONS.²⁾

Although MURRAY³⁾ seems to have differed from OLTMANNS's

1) Cf. SAUNDERS: HARRIMAN's Alaska expedition. Pl. LXII, fig. 1.

2) A morphol. study of Sarg. filip. Pl. X. fig. 22. The Bot. Gazette, vol. 49. 1906.

3) Phyc. Memoir. Part. II. p. 30.

view, in preferring those characters on which the latter rests his sections to that afforded by the growth of the plants, there is no doubt that the occurrence of an apical cell at the growing point characterizes certain groups of Fucaceous genera. Unfortunately the material of the present species in my hands was not fitted for the purpose of examination on this point. But there is little doubt left that our plant belongs to the *Fuco-Ascophyllum* group of OLTMANN, or at least stands nearer to it than to the others.

The uncertainty of the systematic position of the present genus comes from our lack of knowledge of its propagating organ; and there is no positive proof that the foliose and filiform types belong to one and the same species. So far as the vegetative characters of the fronds of the present species shows, the disposition of this genus in the family *Fucaceae* will be the most legitimate one.

I am strongly inclined to believe that the conceptacles, when found in our plant, will be in the filiform type. If this be really the case, what is the use of the foliose frond? If, again, fructification be found on both types, what is the relationship between the two? The solution of these interesting problems must be reserved for future investigations.



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List of Abbreviations.

- (H. S. A.)Herbarium of the Sapporo Agricultural College.
 (H. H. F.)Herbarium of the Department of Fisheries of the Hokkaido Local Government.
 (H. COLL. SC.)...Herbarium of the College of Science, Tōkyō Imperial University.
 (!).....This sign indicates that the specimen has been collected by the present writer or is kept in the writer's herbarium.

Errata.

Page	Line	For	Read
12.	11 from below.	<i>S. confusum f. validum</i> ,	<i>S. confusum f. valida</i> .
18.	8 & 11 from above.	<i>Pelvetia Babingtonii f. japonica</i> ,	<i>Pelvetia Wrightii f. japonica</i> .
„	15 from above.	<i>Pelvetia Babingtonii f. Wrightii</i> ,	<i>Pelvetia Wrightii f. Babingtonii</i> .
20.	8 from below.	E.P. WRIGHT,	P.E. WRIGHT.
26.	6 & 14 from below.	<i>Fucus furcatus f. distichus</i> ,	<i>Fucus inflatus f. distichus</i> .
29.	9 from above.	<i>Cystophyllum hypocarpa</i> KÜTZ.,	<i>Cystoseira hypocarpa</i> KÜTZ.
32.	9 from above.	Plate II., Fig. 13-15.	Plate II., Fig. 13-16.
32, 42, 60, 69, 72, & 73.	In diagnosis.	scutellata,	scutellata.
44.	2 from below.	rhizine,	rhizines.
70.	10 from below.	int,	into.
78.	14 from below.	AGARDH,	J. AGARDH.
91.	7 from above.	<i>Carpacanthus trichophyllum</i> KÜTZ.,	<i>Carpacanthus trichophyllus</i> KÜTZ.
102.	13 from above.	Plate XV., Fig. 1-5,	Plate XV., Fig. 1-4.
112.	9 from above.	<i>f. validum</i> ,	<i>f. valida</i> .
115.	15 from below.	<i>Fucus Thunbergii</i> TURN. &c.,	<i>Fucus Thunbergii</i> MERT. in TURN. &c.

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PLATE I.

Plate I.

(All figures in this and all following plates are in natural size, unless specially mentioned).

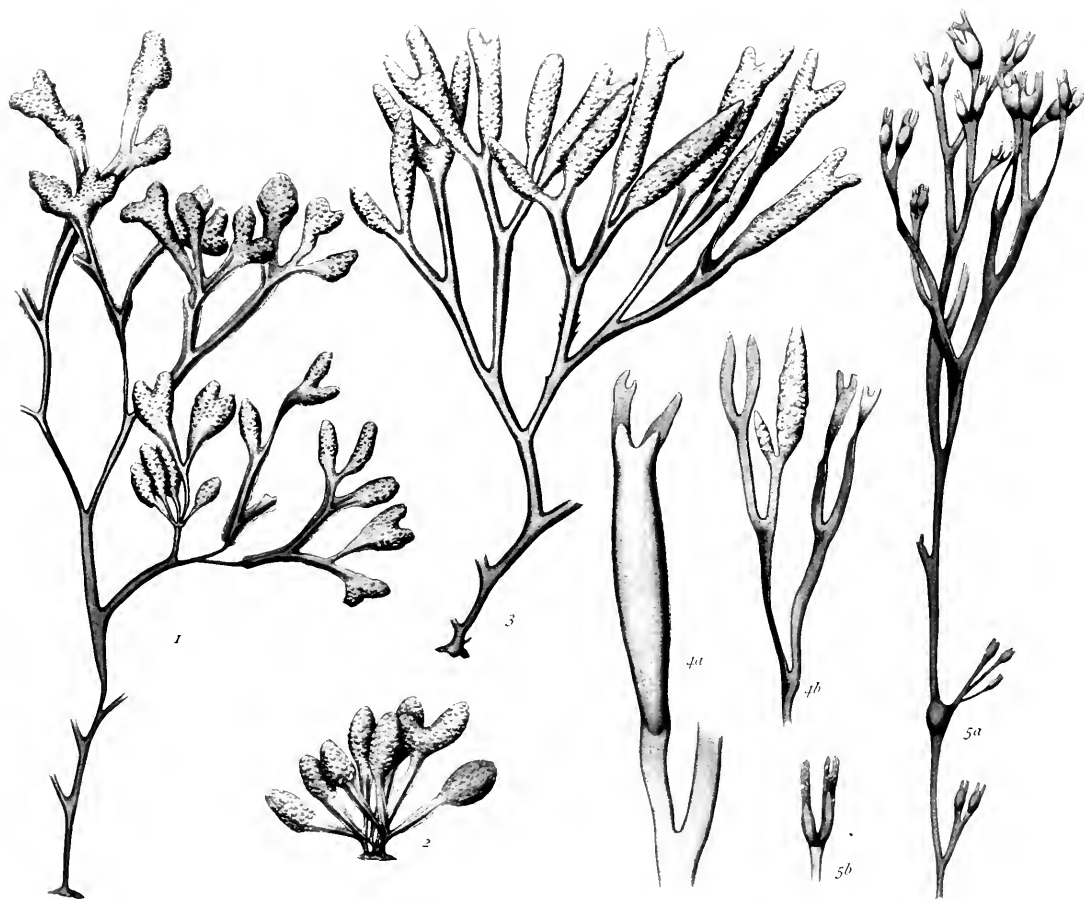
Figs. 1-2. *Fucus evanescens* AG.

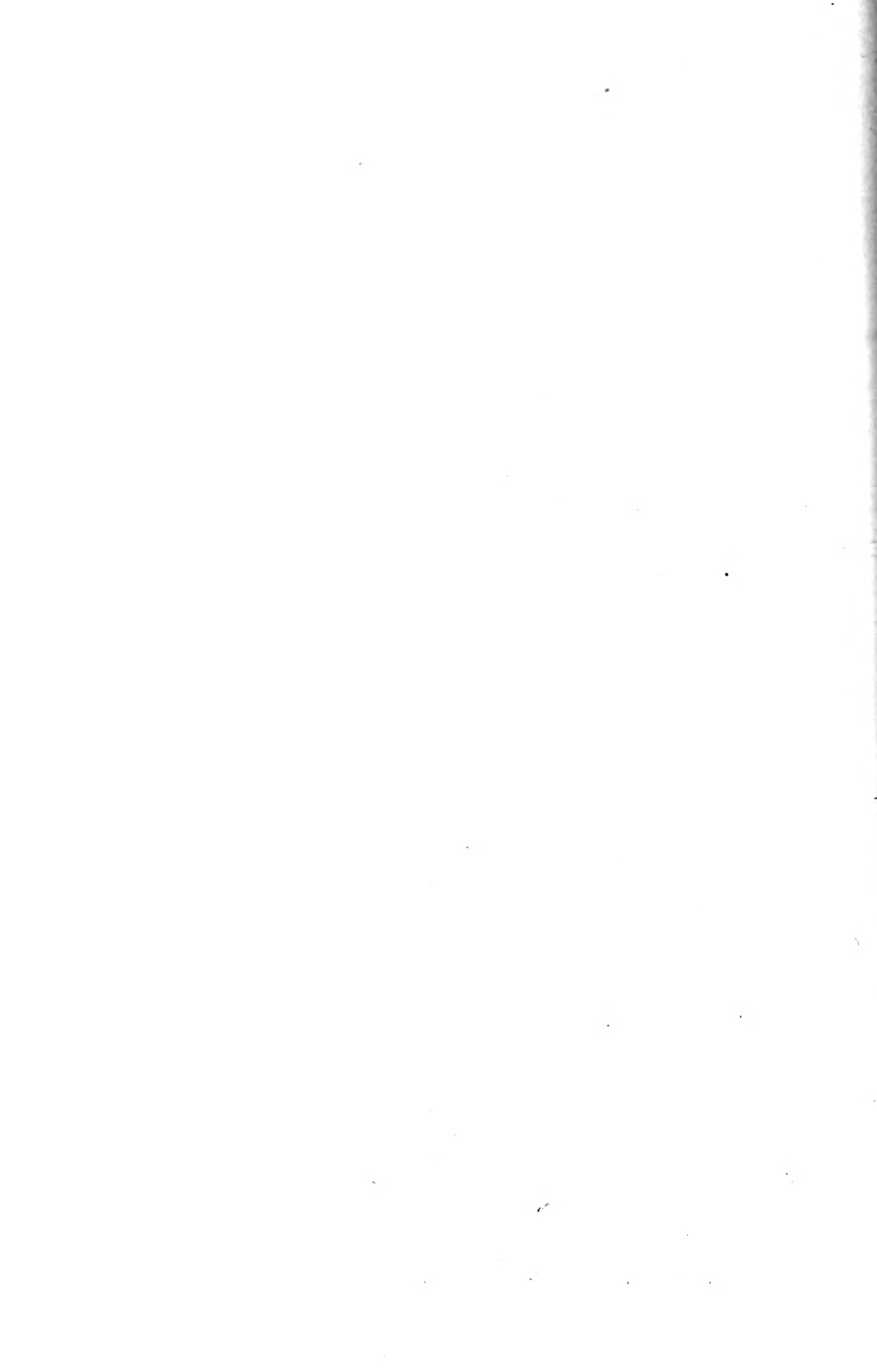
1. From a specimen collected at Omnebetsu, in the prov. of Kitami. This form is referrible to *f. angusta* KJELLM.
2. The same, from a specimen collected at Esashi in the prov. of Kitami. This approaches both *f. nana* KJELLM. and *f. bursigera* KJELLM. at once.

Fig. 3. *Fucus inflatus* VAILL. *f. edentatus* ROSENV.

Fig. 4. *Pelvetia Wrightii* var. *typica*. *a*. An ultimate branch with blister-like ampula. *b*. A fertile branch.

Fig. 5. *Pelvetia Wrightii* var. *japonica*. *a*. A typical branch. *b*. Fertile segments.





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PLATE II.

Plate II.

Figs. 1-8. *Ishige Okamurai*.

1. Frond of the foliose type; one of the broadest fronds in our collections. The ramification is somewhat irregular in this specimen owing to injuries in many parts of the frond.
2. Frond of the foliose type with abnormal foliose branches on one of its segments.
3. Frond of the filiform type with abnormal foliose branches on one of its segments.
4. Cross-section of a frond of the filiform type through an insertion point of two abnormal foliose branches. *a*, filiform frond; *b*, basal portion of a foliose branch; *c*, the swollen part at the insertion of the foliose branches. $\times 15$.
5. Longitudinal section of an apex of a foliose frond. $\times 165$.
6. A part of longitudinal section of a frond of the foliose type; about the middle portion of a frond. $\times 165$.
7. A part of cross section of a frond of the filiform type; about the middle portion of a frond. $\times 165$.
8. Cross section of a frond of the foliose type to show a cryptostoma. $\times 285$.

Figs. 9-12. *Cystophyllum crassipes* J. Ag.

9. Basal portion of a well grown individual.
10. Apical portion of the axial stem with basal parts of incrassate branches.
11. Lateral branches, one of which is fertile. The end marked with \times is to be connected below to the part with the same mark in the preceding figure.
12. Basal region of a branch with a sterile lateral branch.

Figs. 13-16. *Cystophyllum hakodatense*.

13. A young axial stem with many "fusiform" branches, some of which have been cleared away.
14. A young lateral branch growing from the swollen side of a fusiform branch. The part marked with \times is to be connected to the part with the same mark in the preceding figure.
15. A φ fertile lateral branch.
16. φ fertile ramulets with fully developed receptacles.





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PLATE III.

Plate III.

Figs. 1-6. *Cystophyllum sisymbrioides* J. Ag.

1. Basal part of a well grown plant.
2. A principal branch of a sterile frond, with one lateral branch.
3. A portion of withered principal branch; the approximate lateral branches have been worn away, leaving their pinnately disposed basal parts only.
4. A basal leaf at the basal part of a sterile lateral branch; one of the laciniae transformed into vesicle.
5. Same as above, with two transformed laciniae.
6. Upper portion of a fertile lateral branch.

Figs. 7-11. *Cystophyllum Turneri* (Kütz.)

7. Axial stem measuring about 20cm. in length, with the lateral branches cut off near the insertion points. *a*, basal region; *b*, apical region.
8. A leaf at the base of a lateral branch.
9. Vesicles at the basal portions of ramulets.
10. Two consecutive vesicles in a ramulet.
11. Middle portion of a lateral branch with fertile ramulets.

Figs. 12-13. *Cystophyllum caespitosum*.

12. *a, b, c.* Upper, middle and lower portion respectively of a branch of 39cm. length.
13. *a, b.* Upper and middle portion respectively of a branch of 23 cm. length.



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PLATE IV.

Plate IV.

Figs. 1-6. *Turbinaria? fusiformis* (Harv.)

1. A branch of sterile frond.
2. A young frond with leaf-like "rami."
3. The same. *a*, a leaf.
4. A part of fertile branch with cymose receptacles at the axils.
5. The same; a fertile lateral branch growing at the axil formed by a fulcrant "ramus" and the stem.
6. A sterile lateral branch, the fulcrant "ramus" being leaf-like.

Fig. 7. *Forma clavigera*. A branch of sterile frond.

Figs. 8-12. *Coccophora? Imperata*.

8. Frond in ca. $\frac{2}{3}$ nat. size; one branch shown in full.
9. A lateral ramulet in nat. size.
10. A leaf in nat. size.
11. A bifurcated leaf. $\times 2$.
12. A lateral ramulet with upper portions of the basal leaves left out. $\times 10$.



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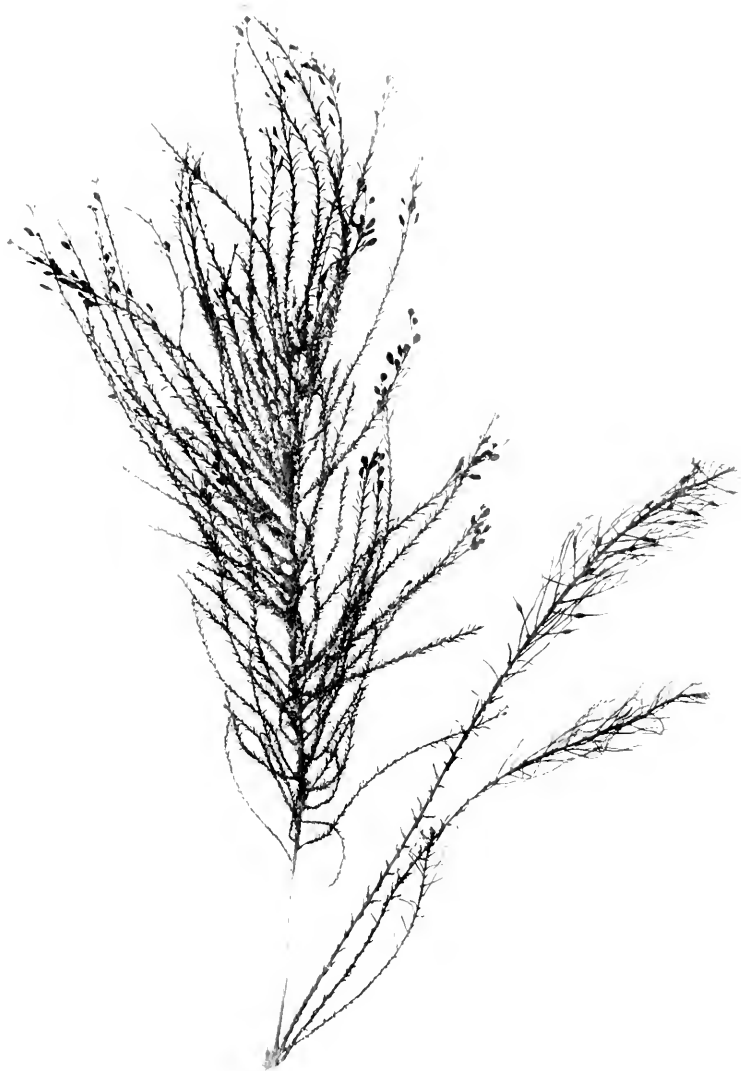
PLATE V.

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Plate V.

Coccophora Langsdorffii GREV.

The Langsdorf and the Phyllamphora form starting from one and the same stunted stem. From a photograph. Ca. $\frac{1}{3}$ nat. size.





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PLATE VI.

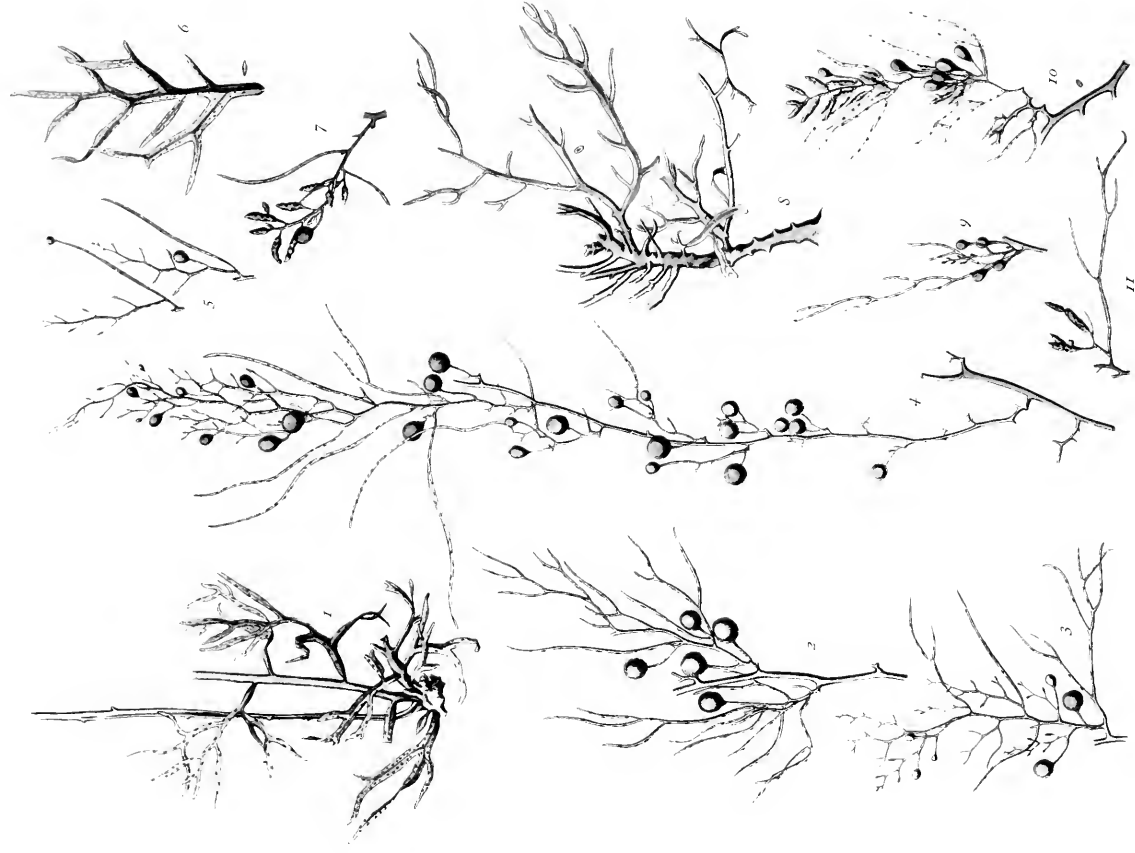
Plate VI.

Figs. 1-7. *Sargassum piluliferum* Ag.

- 1, 2 and 3. Basal, middle and upper portion respectively of a frond; in fig. 2 the upper portions of the lateral branches are left out.
4. A fertile branchlet in a full-grown lateral branch, whose uppermost portions are left out.
5. Ramulets with young receptacles.
6. A leaf at the basal part of a frond.
7. A fertile ramulet with mature ♀ receptacles. $\times 2$.

Figs. 8-11. *Sargassum piluliferum* var. *pinnatifolium* (Ag.)

8. Basal portion of a frond.
9. A receptacular ramulet on a lateral branch.
10. A part of a fertile lateral branch.
11. A receptacular ramulet on the apical part of a frond.



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PLATE VII.

Plate VII.

Figs. 1-3. *Sargassum pinnatifidum* (HARV.)

1. Sterile lateral branches in the lower region of a frond; from a specimen collected at Misaki.

2 and 3. Lateral branches in the upper and the middle portion of a frond respectively; from a specimen collected in Loochoo.

Fig. 4. *Sargassum kashiwajimianum*.

Middle portion of a frond, showing typical fulcrant leaves.

Figs. 5-7. *Sargassum setaceum*.

5. Basal portions of two shoots starting from a common scutellate root.

6. A lateral branchlet in the lower portion of a frond.

7. Lateral branches germinate at an axil; one of them not drawn in its upper portion.





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PLATE VIII.

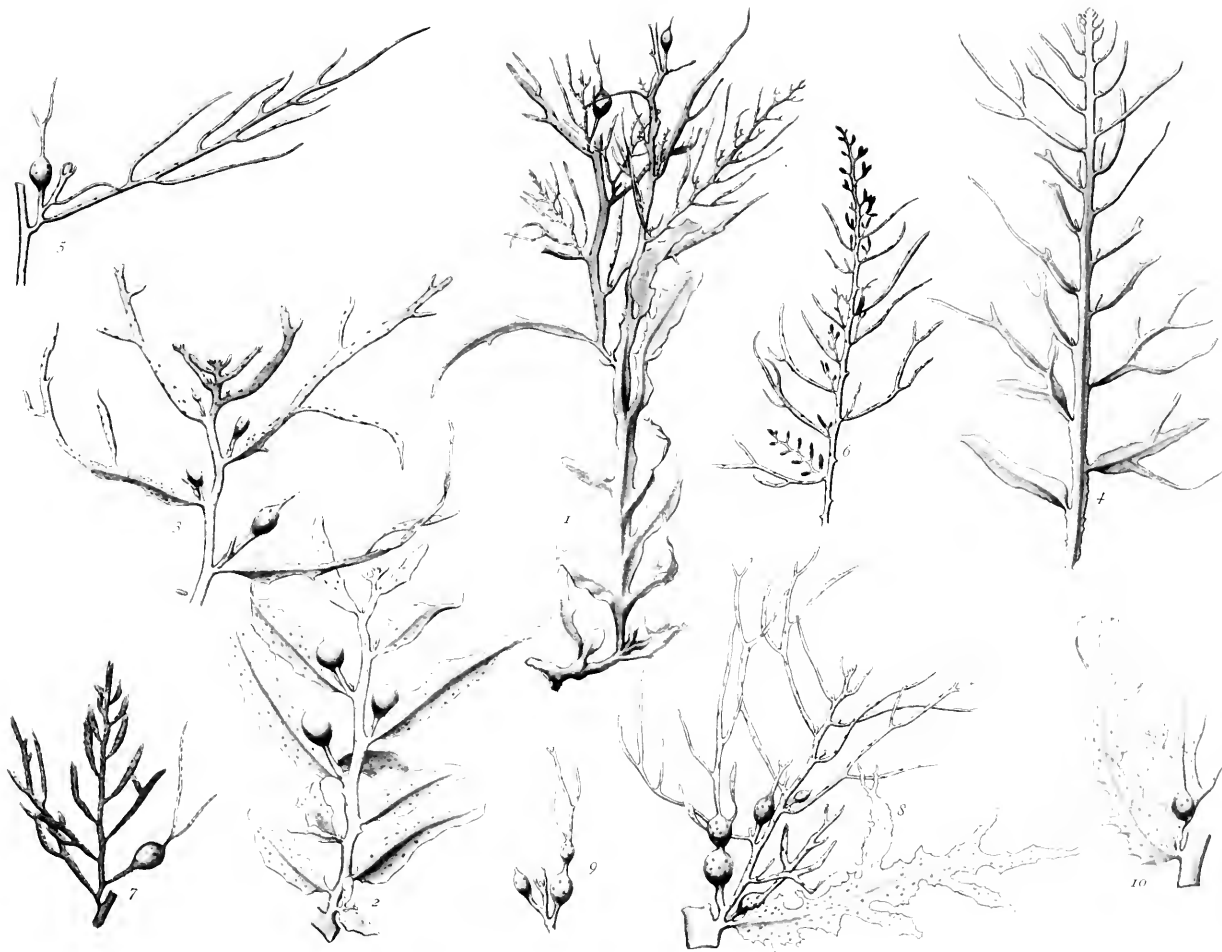
Plate VIII.

Figs. 1-7. *Sargassum patens* Ag.

1. Basal portion of a frond showing the lower region of a principal branch.
2. A lateral branch in the basal region of a frond.
3. Apical portion of a sterile principal branch.
4. A lateral branch in the lower part of a well-developed principal branch.
5. A ramulet on a lateral branch of the frond shown in fig. 4.
6. Apical portion of a lateral branch.
7. A mature receptacular ramulet.

Figs. 8-10. *Sargassum patens* var. *Schizophylla* (Kütz.)

8. A lateral branch in the lower portion of a frond.
9. A young lateral branch.
10. A lateral branch in the middle portion of a frond.



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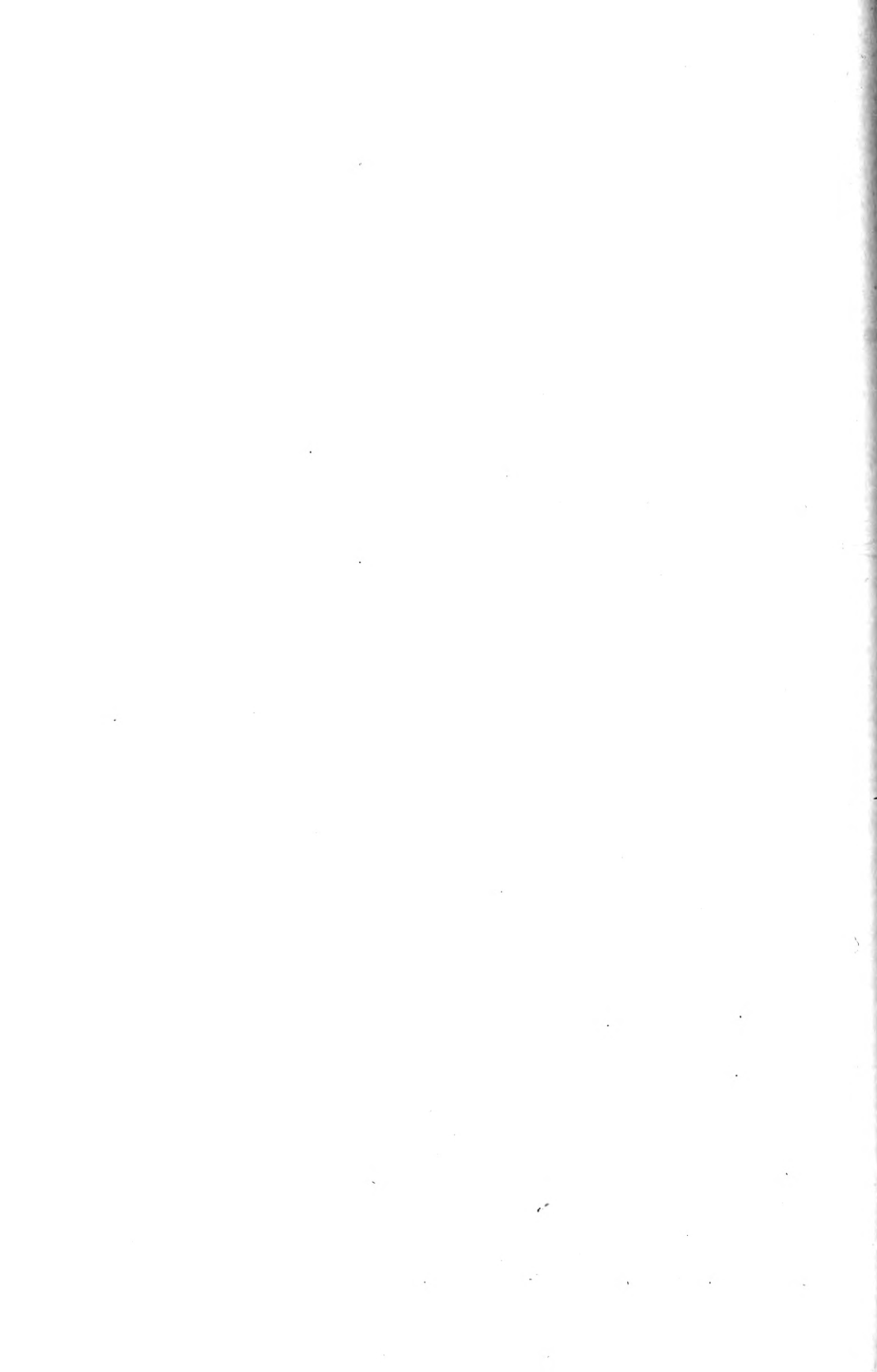
PLATE IX.

Plate IX.

Figs. 1-4. *Sargassum tosaense*.

1. Basal portion of a frond.
2. Lower portion of a lateral branch. The fulcrant leaf as well as the three leaves on the lateral branch show well the peculiarity of the species.
3. A fertile lateral branch in the upper portion of a frond.
4. A simple fulcrant leaf often met with in the lower part of a well developed frond.





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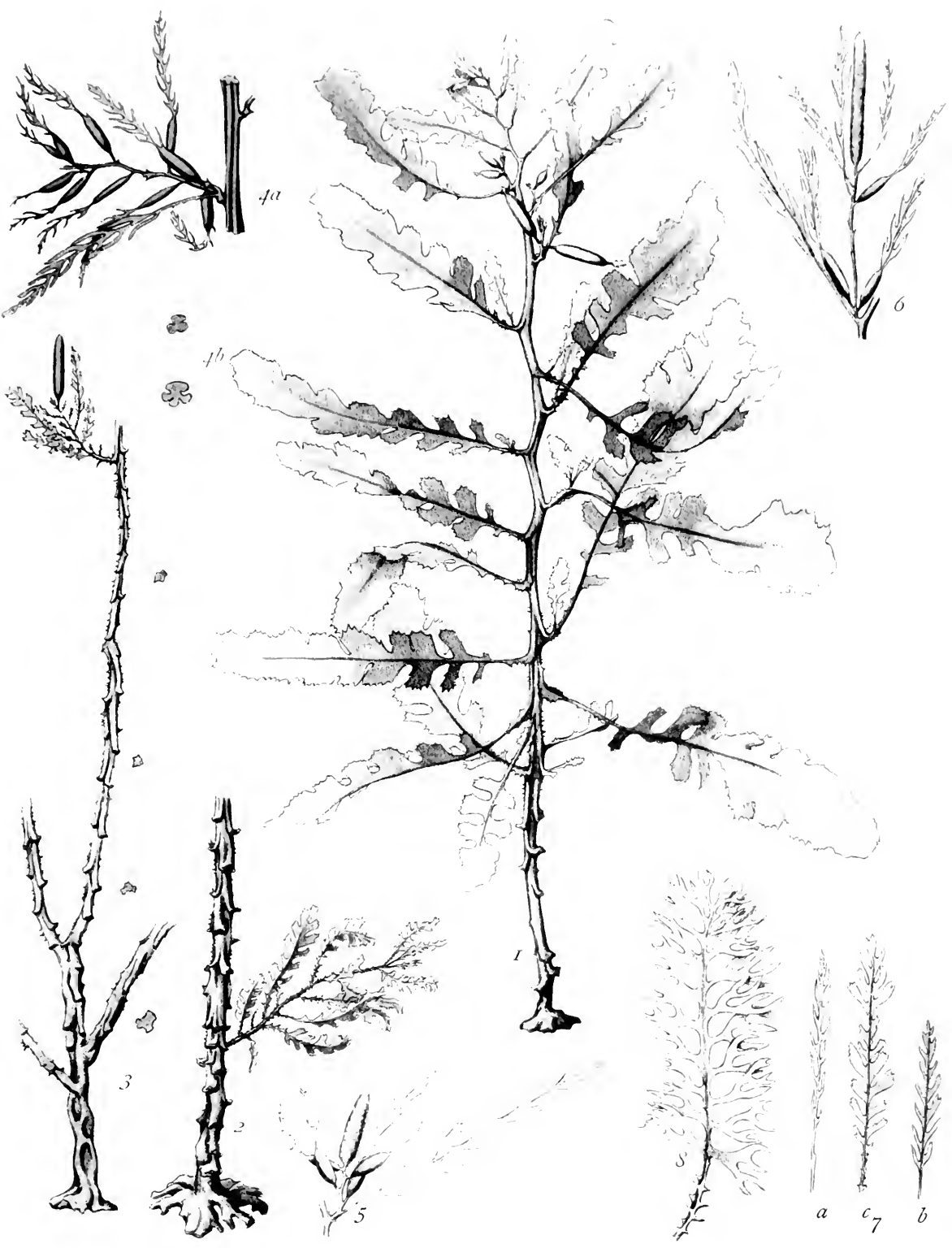
PLATE X.

Plate X.

Figs. 1-7. *Sargassum Horneri* Ag.

1. A sterile young frond.
2. Basal part of an old plant with a lateral branch.
3. Basal part of a well developed plant showing naked basal stems and a lateral branch, with cross-sections of stems.
4. *a*, Insertion point of an upper lateral branch. *b*, cross sections of the stem. $\times 2$.
5. A ♀ fertile branchlet.
6. A ♂ fertile branchlet.
7. *a*, *b*, *c*, Leaves on the terminal, middle and basal part respectively of a terminal branchlet.

Fig. 8. *Sargassum Horneri* f. *furcatodentatum* O'KUNTZE.
A typical fulcrant leaf. $\times 2$.





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PLATE XI.

Plate XI.

Figs. 1-7. *Sargassum serratifolium* Ag.

1. Terminal portion of a well developed but sterile frond.
2. Basal portion of the same.
3. Basal portion of a full-grown frond.
4. Middle portion of the same ; with a crosssection of the stem.
5. A typical lateral branch just before maturity ; with cross-sections of stems.
6. Basal region of a fertile lateral branch to show the receptacular ramulets. The lower ramulet has all its bractlets dropped off. With a cross-section of the stem.
7. A typical leaf.





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PLATE XII.

Plate XII.

Figs. 1-7. *Sargassum tortile* Ag.

1. A sterile branch in the basal region of a well developed frond; with cross section of the stem.
2. A young principal branch. In this sort of branches the leaves are not refractive.
3. Basal part of a full-grown plant, showing the copious ramification; each branch is cut off near at its insertion point.
4. Lower portion of a frond collected at Hamajima, Prov. of Shima. This form answers to that which was mentioned by KÜTZING under the name *Halochloa pachycarpa*. With cross section of the stem.
5. *a.* A fertile lateral branch in the upper portion of a matured frond; not a single leaf is to be found on it. This sort of branch, when there is no leaf on it, is often difficult to distinguish from *Sargassum serratifolium*. If, however, even a single leaf remain attached to it as shown in fig. 5*b*, it can be safely be referred to this species.
6. A typical fertile ramulet.
7. Densely pinnatifid lateral branch, often found in the lower part of a frond.

Fig. 8. *Sargassum tortile* f. *macrocarpum* (Ag.)

A fertile lateral branch. In the present specimen most of the receptacles lack the bractlet. In others, however, each receptacle, except the ultimate ones, is supplied with a bractlet as shown in fig. 6. With cross-sections of various parts of the stems.

Fig. 9. *Sargassum filicinum* HARV.

A fertile ramulet.



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PLATE XIII.

Plate XIII.

Figs. 1-6. *Sargassum enerve* Ag.

1. *a*, Middle portion of a fertile frond, showing a characteristic lateral branch. *b*, cross sections of the principal stem. *c*, a typical leaf on the lateral branches.
2. A fertile lateral branch from the upper portion of the same individual as shown in fig. 1.
3. *a*, *b*, Receptacular ramulets. In *b*, a receptacle bears a minor receptacle accompanied with a bractlet.
4. Terminal portion of a full-grown sterile frond.
5. A typical, young lateral branch of the same.
6. Lower portion of the same frond, with a cross-section.

Figs. 7-17. *Sargassum hemiphyllum* Ag.

7. Basal portion of a frond with symmetrical leaves.
8. Middle portion of the same frond, with lateral branches, two of the fulcrant leaves still remaining attached.
9. A young lateral branch. ca. $\times 3$.
10. Insertion point of a full-grown lateral branch.
11. Vesicles with a flat, short crown leaflet. $\times 2$.
12. A ♀ receptacular ramulet of the form typical of the species. ca. $\times 3$.
13. A receptacular ramulet from a south-sea form.
14. Basal portion of a frond with hemiphyllous basal leaves.
15. A lateral branch in the upper part of the same.
16. Large fulcrant leaves on well-developed sterile fronds.
17. Marginated vesicles.

Figs. 18-20. *Sargassum fulvellum* Ag.

18. Basal part of a well-grown fertile plant, with cross-sections of the stems.
19. Upper portion of a branch of the plant illustrated in fig. 18; the lower end marked with \times is to be connected to the upper end with the same mark in fig. 18. In this branch the receptacles are not yet fully mature.
20. Terminal portion of a branchlet with ♂ receptacles. ca. $\times 2$.



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PLATE XIV.

Plate XIV.

Figs. 1-7. *Sargassum confusum* Ag.

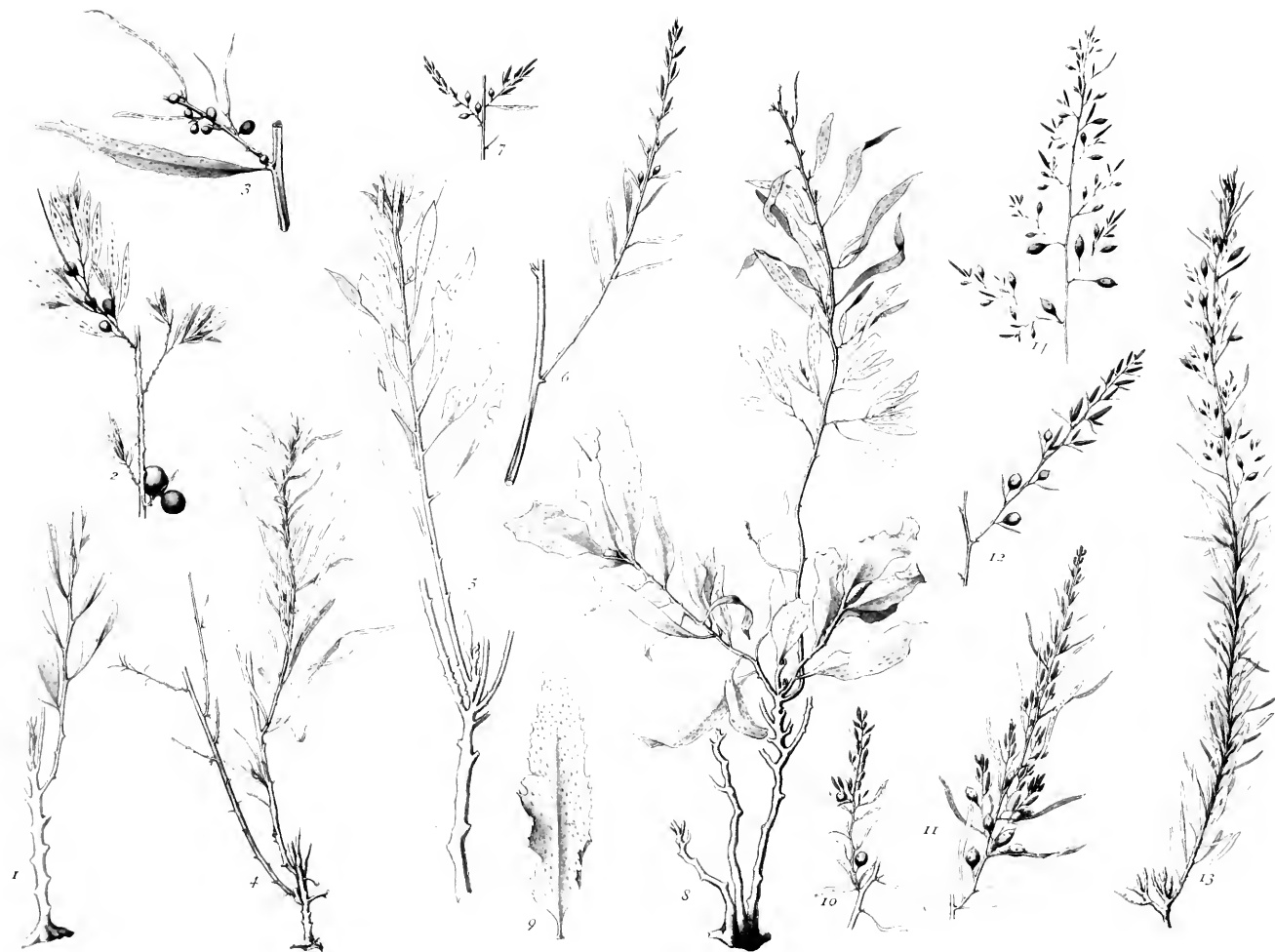
1. Basal part of a plant with a young branch.
2. Middle portion of a principal branch with four lateral branches, the fulcrant leaves of which have dropped off.
3. Basal part of a lateral branch with its fulcrant leaf remaining attached.
4. Basal part of a plant destitute of the broad basal leaves.
5. Lower portion of a well-developed plant with a sterile branch. In this plant all the vesicles were aristated.
6. A fertile lateral branch in the middle part of a principal branch; from the same frond shown in the preceding figure. The lower end marked with \times is to be connected to the point with the same mark in fig. 5 with some intermediate space between.
7. Fertile ramulets from the upper space of a lateral.

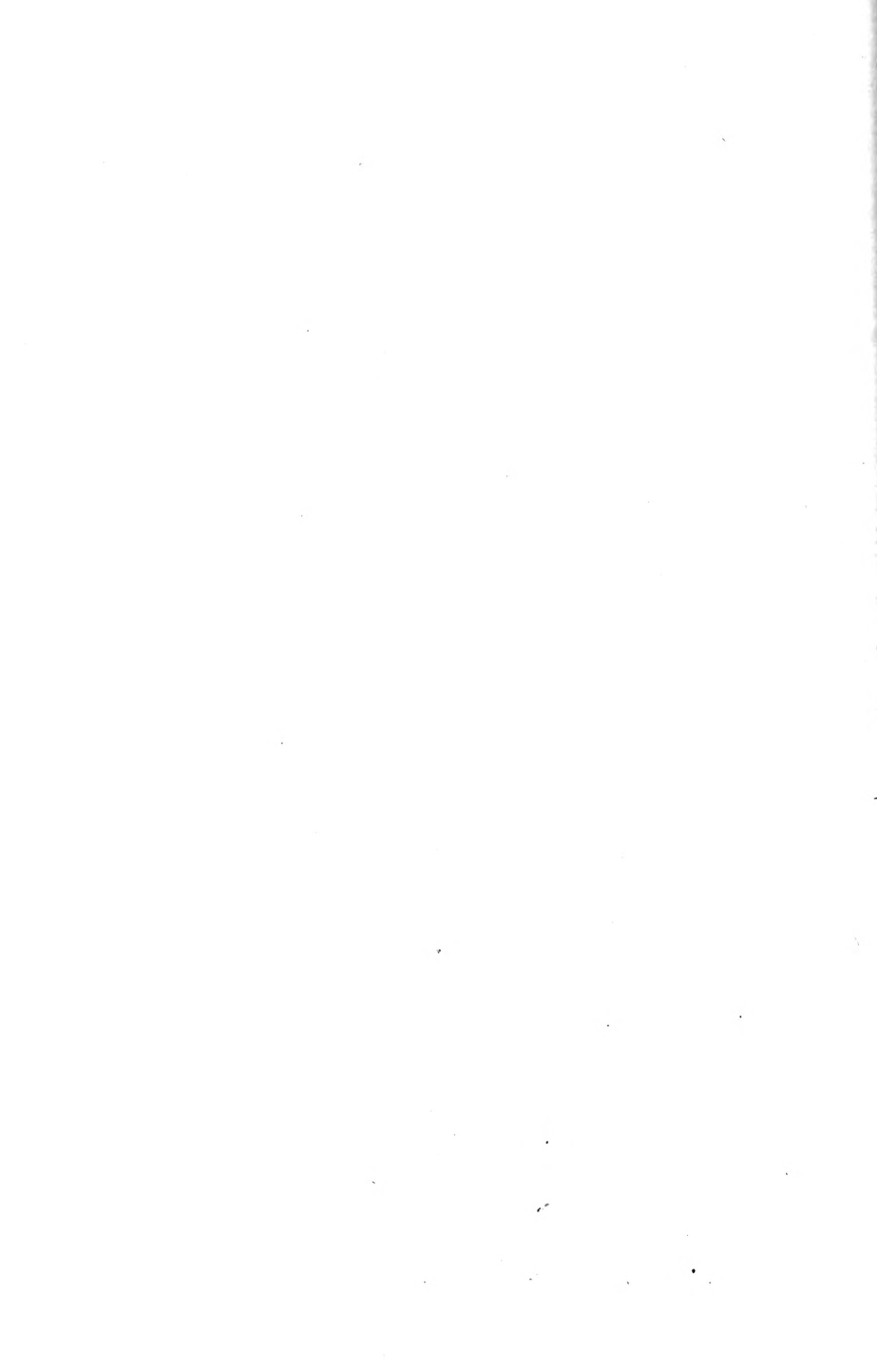
Figs. 8-12. *Sargassum confusum* f. *valida* (J. Ag.)

8. Basal part of a well-developed fertile plant with sterile young branches and with middle portion of a branch of a more advanced stage.
9. A typical basal leaf.
10. A fertile ramulet from the upper part of the branch which is marked in fig. 8 with \times .
11. A lateral branch with several fertile ramulets.
12. A fertile ramulet from a well-developed plant.

Figs. 13-14. *Sargassum Miyabei*.

13. A middle sized principal branch, showing basal portion of the plant.
14. Apical portion of a branch with well-developed receptacular ramulets.





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PLATE XV.

Plate XV.

Figs. 1-4. *Sargassum Kjellmanianum*.

1. Basal part of a plant, with a very young branch at the base.
2. Middle portion of a branch with a fertile lateral branch.
3. A fertile ramulet. ca. $\times 3$.
4. A part of a fertile ramulet showing the vesiculiferous receptacles. ca. $\times 3$.

Fig. 5. *Sargassum Thunbergii* f. *nipponica*.

A portion of a principal branch, showing three nodes and two stunted fertile ramulets. In the right hand ramulet the fulcrant leaf is filiform lanceolate, and in the left hand one it assumes a vesicular form. ca. $\times 5$.

Figs. 6-9. *Sargassum kiushianum*.

6. Middle portion of a frond, with a cross-section of the stem.
7. A receptacle with a leaf at the basal part of its stipe. The leaf as well as the fulcrant leaf is partly shown. ca. $\times 4$.
8. Receptacles seen from the elevated side. ca. $\times 4$.
9. Cross section of receptacle. ca. $\times 5$.

Figs. 10-17. *Sargassum micracanthum* (Kütz.)

10. Basal part of a well-developed plant, with cross-sections of the stem. Observe many young shoots are starting from the same root.
11. A typical lateral branch in the upper portion of a sterile frond.
12. The same near at the apical portion of a well-developed sterile frond.
13. A fertile lateral branch in the upper portion of a full-grown frond.
14. A fertile branch from a comparatively small plant.
15. A fertile ramulet near the terminal portion of a frond.
16. The same from a well-developed frond.
17. Cross section of a ♂ receptacle Ca. $\times 8$.

Figs. 18-21. *Sargassum micracanthum* var. *stipulata*.

18. Basal part of a plant. Observe the basal leaves are entire, as in the typical form (fig. 10).
19. A fertile lateral branch.
20. Insertion point of well developed lateral branches, with one fulcrant leaf still remaining. Observe the vesicles are coronated and slightly winged.
21. A typical fulcrant leaf.





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PLATE XVI.

Plate XVI.

Figs. 1-3. *Sargassum nigrifolium*.

1. A young sterile branch.
2. Middle portion of a full-grown frond, showing ♀ fertile lateral branches.
3. Part of a fertile lateral branch to show the arrangement of receptacular ramulets.

Fig. 4. *Sargassum graminifolium* Ag.

A fertile lateral branch, from a specimen from Prov. of Awa.
Cf. text p. 130.

Figs. 5-9. *Sargassum Ilivifolium* var. *duplicatum* J. Ag.

5. Receptacular ramulet, with most of the receptacles spinescent. Ca. $\times 2$. (from a specimen collected at Hiratsuka, Prov. of Sagami).
6. The same, with some of the receptacles smooth; from the same branch which bears the ramulet shown above. Ca. $\times 2$.
7. A fertile lateral branch, probably of the present species. (From a specimen from Prov. of Tosa. Cf. Text. p. 132). ♂.
8. A receptacular ramulet of the same. Ca. $\times 2$.
9. A receptacle cluster enlarged.

Figs. 10-14. *Sargassum beriberifolium* J. Ag.

10. Basal part of a well-developed plant.
11. A fertile lateral branch in the middle part of a branch.
12. The same with a vesicle.
13. A receptacle cluster enlarged.
14. A typical leaf.

Figs. 15-16. *Sargassum cinctum* J. Ag.?

15. A fertile lateral branch. ♀.
16. A receptacle cluster enlarged.

Fig. 17. *Sargassum microphyllum* Ag.?

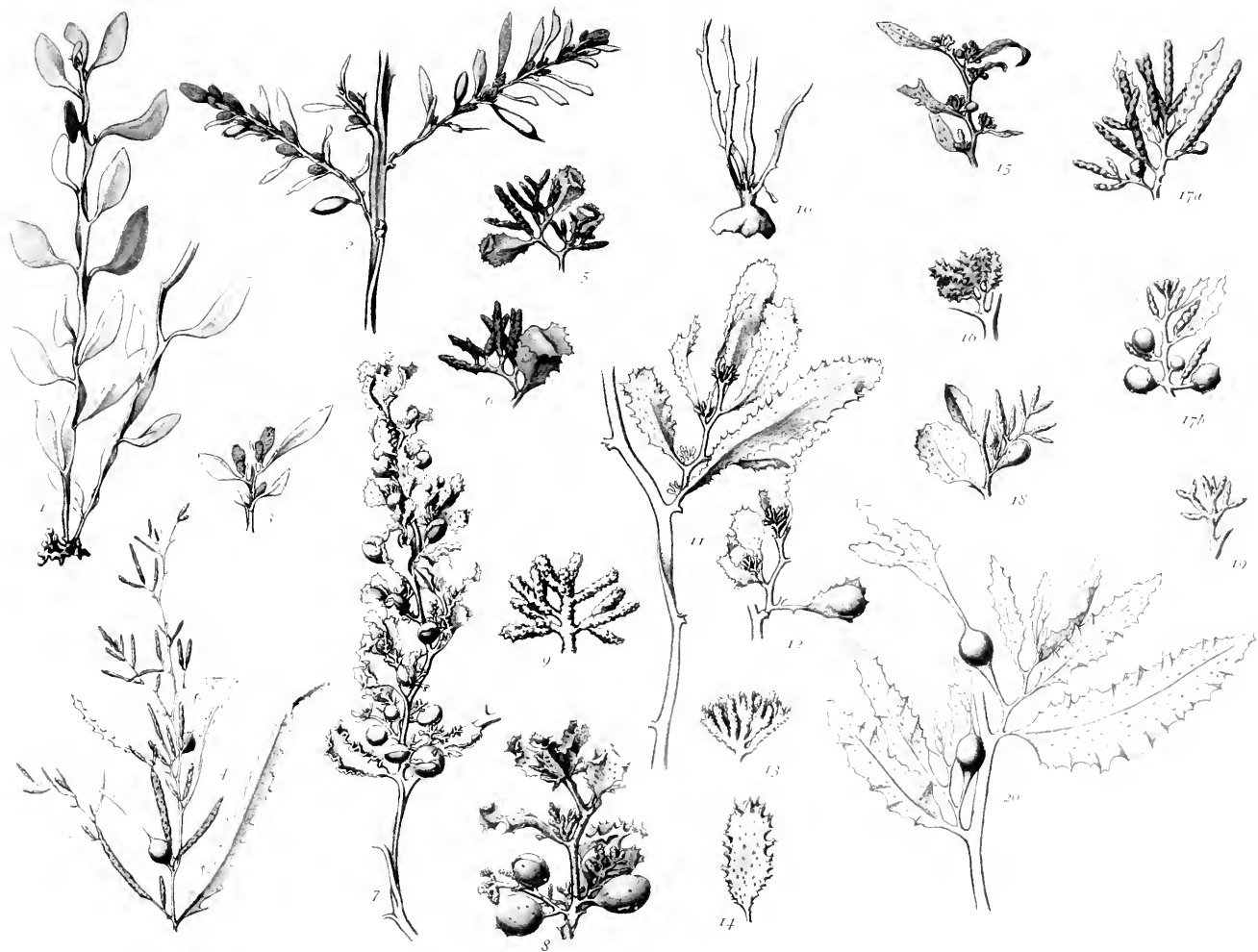
a, b. Two receptacular ramulets. Ca. $\times 4$.

Figs. 18-19. *Sargassum aquifolium* forma.?

18. A part of a fertile lateral branch. Ca. $\times 2$
19. A receptacle cluster. Ca. $\times 3$.

Fig. 20. *Sargassum kashimotoense*.

A part of the frond showing two sterile lateral branches.



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PLATE XVII.

Plate XVII.

- Fig. 1. *Sargassum siliculosum* J. Ag.
The upper part of a sterile frond, with the peculiar ampullated leaves.
- Figs. 2, 3. *Sargassum assimile* var. *stipulata*.
2. A full-grown lateral branch from near the middle of a frond.
3. Lower portion of the same frond. In both figs. 2 & 3 the ends marked with \times are continuous with some intervening space.
- Fig. 4. *Sargassum vulgare* var. *foliosissimum* J. Ag.
A receptacular ramulet. Ca. $\times 2\frac{1}{2}$.
- Fig. 5. *Sargassum vulgare* var. *linearifolium* J. Ag.
a. A part of a branch with a fertile lateral branch.
b. A receptacular ramulet. Ca $\times 3$.
- Figs. 6-10. *Sargassum saianianum*.
6. The knotty root. A young branch and a part of a well-grown branch are shown in the figure; other branches are all left out.
7. Middle portion of a well-grown branch with two lateral branches. The end marked with \times is to be connected with the same-marked end in the preceding figure.
8. Lower portion of a full-grown branch.
9. Basal portion of a full-grown lateral branch.
10. A young sterile branch with the second leaves.
- Figs. 11-16. *Sargassum nipponicum*.
11. Lower portion of a frond.
12. Apical part of a principal shoot.
13-16. Receptacular ramulets in various stages of development.





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PLATE XVIII.

Plate XVIII.

Figs. 1-9. *Sargassum Ringgoldianum* HARV.

1. A sterile frond with some parts left out.
3. Basal portion of a well-developed plant showing dichotomously branching stems.
4. Insertion point of a lateral branch. In this as in the next figure the fulcrant leaf is transformed into a large vesicle.
5. A fertile lateral branch with ♀ receptacles. *b*, cross-section of a receptacle. Ca. $\times 4$.
- 6-8. ♂ Receptacular branches of various forms; those in figs. 7 and 8 are somewhat decayed with age. *6 b*, cross-section of a receptacle. Ca. $\times 4$.
9. Vesicles with winged margins.





